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Highway Lighting Test Bed at INDOT Facility (Off-Roadway)

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16. Abstract

According to the National Highway Traffic Safety Administration (NHTSA), during 2016 there were 7,277,000 vehicle crashes nationally. Among them, approximately 70% happened during the daytime and around 30% of crashes occurred during the nighttime. There were 11,375 nighttime fatal crashes that account for about 48% of total fatal crashes (23,714). Given the fact that only 25%–33% of the vehicle miles traveled (VMT) occur at night, the above statistics indicate that the nighttime crash fatality rate is much higher and nighttime crashes are usually more severe compared to daytime crashes. Providing lighting on roadways is one of the proven safety countermeasures for preventing crashes and reducing fatalities. In particular, lighting at roadway intersections can reduce vehicle crashes by 10% to 26%. Currently, to conduct lighting field testing, INDOT is using several in-service highways, intersections, interchanges, and rest areas. These locations require traffic control and lane closures, which raises safety concerns and causing inconvenience to the public. In addition to the cost and safety concerns, during the evaluation period the new luminaires being tested actually functioned as lighting sources in place of the existing luminaires that were removed in order to install the new luminaires. This means that the new luminaries were used for roadway lighting at the test sites even before they were proven to meet the roadway lighting requirements.

To eliminate traffic control and potential safety concerns, it was proposed to create test beds for field evaluating and to verify the performance of new lighting technologies and luminaires in a controlled, standard setting. Through this study, two lighting test bed facilities were designed and constructed. Illuminance values of installed luminaires were manually measured by a remotely controlled electric cart and drone. The measured illuminance values were analyzed and the analysis indicated that the efficiency of illuminance measurement can be significantly improved by automated methods. An illuminance data repository model was developed to be an effective tool that can greatly facilitate data input and storage process. The use of this model will further increase the productivity of illuminance measurement at the lighting test beds.

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EXECUTIVE SUMMARY

Introduction

According to the National Highway Traffic Safety Administration (NHTSA), in 2016 there were 7,277,000 vehicle crashes nationally. Approximately 70% of crashes occurred during the daytime and around 30% of crashes occurred during the nighttime. There were 11,375 nighttime fatal crashes that account for about 48% of total fatal crashes (23,714). Given the fact that only 25%–33% of the vehicle miles traveled (VMT) occur at night, the above statistics indicate that the nighttime crash fatality rate is much higher and nighttime crashes are often more severe compared to daytime crashes. Driving at nighttime is inherently demanding, but providing lighting on roadways is one of the proven safety countermeasures for preventing crashes and reducing fatalities. In particular, lighting at roadway intersections can reduce vehicle crashes by 10% to 26%. Improved visibility offered by new light source technologies enhances drivers' ability to obtain information quickly.

As part of the effort to improve nighttime roadway safety, INDOT has evaluated several emerging new lighting technologies and their safety effects on roadways and intersections through JTRP research projects. One of these research projects won the 2017 AASHTO National Sweet Sixteen High Value Projects Award. The evaluated new lighting technologies include light emitting diode (LED), induction, and light emitting plasma. Crash modification factors were also developed to quantify safety effects of roadway lighting. The field test data and research results have been used to upgrade INDOT's practices for roadway lighting, the standard specifications for luminaires, and the field-testing procedure for luminaire approval.

Currently, to conduct this field testing, INDOT is using several in-service highways, intersections, interchanges, and rest areas. These locations require traffic control and lane closures, which raises safety concerns and inconveniences the public. Traffic control and lane closures not only incur labor and operation costs, but also pose safety concerns to both motorists and INDOT personnel. In addition to the cost and safety concerns, during the evaluation period, the new luminaires being tested actually functioned as lighting sources in place of the existing luminaires that were removed in order to install the new luminaires. This means that the new luminaries were used for roadway lighting in the test sites even before they were proven to meet the roadway lighting requirements. To eliminate traffic control and potential safety concerns, it is essential to establish test beds so that new luminaire models can be tested in a controlled, standard setting. It was therefore proposed to establish test beds for field evaluation and performance verification of new lighting technologies and luminaires in support of the formally adopted Indiana Test Method for approving luminaires. In addition, well designed and constructed test beds would make luminaire evaluations comprehensive and accurate according to operation conditions such as weather (temperature and precipitation), on-off cycling, and maintenance. The primary objective of this study was to design, construct, and operate two test beds for INDOT to evaluate new and emerging luminaire models for roadway and underpass applications, according to the Indiana Test Method for approving luminaires today and in the future. The secondary objective of this study was to upgrade the default data utilized by INDOT engineers for the design, calculation, or simulation of roadway lighting.

Results and Findings

In order to improve the efficiency and flexibility of illuminance measurement, this study introduced an idea for automation. A small remote-controlled electrical cart and a drone were used as carriers to achieve automated measurement. By comparing the measurement results generated in different ways, it was found that the roadside, average, and maximum illuminance obtained by point-to-point measurement and cart auxiliary measurements are almost the same. AGi32 software was involved to simulate light measurement. Through comparison, the discrepancies were minimized between the simulation data and the field measurement data by adjusting the modeled lumen depreciation. When the efficiency is at a certain level, the simulation results are close to the actual illuminance values. It is suggested that the AGi32 be calibrated using the measured illuminance values in the lighting test beds. The lighting test beds in the Indianapolis and West Lafayette sites provide INDOT with effective facilities to evaluate new roadway lighting technologies under controlled conditions. The use of lighting test beds will completely eliminate the need for traffic control in field testing roadway and underpass models. Consequently, the risk of crashes with illuminance measurements adjacent traffic flows is also eliminated.

The efficiency of illuminance measurement can be greatly enhanced by using remotely controlled carts and drones. Although a drone cannot measure the illuminance on the pavement surface due to the safety sensor mechanism, it can be used to measure illuminance at different heights so that the light intensities in the vertical direction can be examined and analyzed. That is, the illuminance values can be measured at additional heights rather than the two fixed pole heights, 40 feet at the Indianapolis site and 25 feet at the West Lafayette site. The illuminance data repository model is an effective tool that can greatly facilitate data input and storage processes and further increase the productivity of illuminance measurement at the lighting test beds.

Implementation

The following recommendations to implement the research results are provided.

- Implementation started with the lighting test bed at the Indianapolis subdistrict site in May 2022. The lighting test bed is being used to evaluate new luminaires. The constructed lighting test bed at the West Lafayette site can be used as soon as needed to evaluate new lighting devices and luminaires that are submitted to INDOT for approval.
- The efficiency of illuminance measurement can be significantly increased by using remote-controlled electric carts and/or drones. An implementation phase may be needed to choose the appropriate devices and provide necessary training for illuminance measurement and data handling.
- It is recommended that a cart with sufficient power be used for illuminance measurement so that the cart is able to carry the illuminance meter forward smoothly during measurement. A drone should be used to analyze the vertical distribution of illuminance. A backup battery is needed for the drone to avoid unnecessary delays during illuminance measurement. The illuminance data repository model should be used for data input, storage, and analysis to further increase the productivity of illuminance measurement and evaluation.

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1. INTRODUCTION

1.1 Problem Statement

According to National Highway Traffic Safety Administration (NHTSA), during 2016, there were 7,277,000 vehicle crashes nationally. Among them, approximately 70% happened during the daytime and around 30% of crashes occurred during the nighttime. There were 11,375 nighttime fatal crashes that account for about 48% of total fatal crashes (23,714). Given the fact that only 25%–33% of the vehicle miles traveled (VMT) occur at night, the above statistics indicate that the nighttime crash fatality rate is much higher and nighttime crashes are commonly more severe compared with the daytime. Driving during the nighttime is inherently demanding. Providing lighting on roadways is one of the proven safety countermeasures of preventing crashes and reducing fatalities (Box, 1989). In particular, lighting at roadway intersections can reduce vehicle crashes by 10% to 26% (Zhao et al., 2017). Improved visibility offered by new light source technologies enhances drivers' ability to obtain information quickly.

As part of the effort to improve nighttime roadway safety, INDOT has evaluated several emerging new lighting technologies and their safety effects on roadways and intersections through JTRP research projects. One of these research projects won the 2017 AASHTO National Sweet Sixteen High Value Projects Award. The evaluated new lighting technologies include light emitting diode (LED), induction, and light emitting plasma. Crash modification factors were also developed to quantify safety effects of roadway lighting. The field test data and research results have been utilized to upgrade INDOT's practices for roadway lighting and the standard specifications for luminaires. The research projects also helped in creating the field-testing procedure for luminaire approval.

Currently to conduct this field testing, INDOT is using several in-service highways, intersections, interchanges, and rest areas. These locations require traffic control and lane closures thus raising safety concerns and causing inconvenience to the public. Traffic control and lane closures not only incur labor and operation costs, but also pose safety concerns to both INDOT personnel and motorists. In addition to the cost and safety concerns, during the evaluation period, the new luminaires being tested actually function as lighting sources in place of the existing luminaires that are removed in order to install the new luminaires. This means that the new luminaries are used for roadway lighting in the test sites even before they are proved to meet the roadway lighting requirements. To eliminate traffic control and potential safety concerns, it is essential to establish necessary test beds so that new luminaire models can be tested in a controlled and standard setting. It was therefore proposed to establish test beds for field evaluating and verifying performance of new lighting technologies and luminaires. The test beds are needed in support of the formally adopted Indiana Test Method for approving luminaires. In addition, well designed and constructed test beds would make luminaire evaluations comprehensive and accurate according to operation conditions such as weather (temperature and precipitation), on-off cycling, and maintenance. The primary objective of this study was to design, construct, and operate two test beds for INDOT to evaluate new and emerging luminaire models for roadway and underpass applications, according to the Indiana Test Method for approving luminaires today and in the future. The secondary objective of this study is to upgrade the default data utilized by INDOT engineers for design, calculation, or simulation of roadway lighting.

1.2 Literature Review

Two studies (Li et al., 2013; Zhao et al., 2017) have been conducted in Indiana to develop a procedure for evaluation and approval list requirements for solid state ballasted luminaires (INDOT, 2017). In these two studies, to evaluate new lighting products the new luminaires were installed to the existing in-service roadways. The light levels, color characteristics, and power consumption were measured twice over a period of at least 3 months.

In their study, Mastan and Prisaca (2021) investigated the optimal lighting level that could improve highway safety and also reduce environmental impact. They concluded that the use of photovoltaic panels as highway lighting can reduce the number of road accidents and does not harm future generations by depleting limited natural resources.

A study by Mukta et al. (2020) also explored possible solutions to boost the efficiency of the existing lighting system. The study results were presented to identify and organize the literature into several categories, including fundamental design principles with their advantages, disadvantages, and research challenges.

An advanced cross-sectional method was used to evaluate the effect of adding highway lighting on the safety performance of expressways (Abuzwidah et al., 2020). The study evaluated the safety effectiveness of highway lighting on the night-time crashes on four-lane expressway in the rural areas. The results showed that highway lighting had a positive effect on crash reduction by an approximately 30% for the night-time crashes. The night-time fatal and serious injury crashes were reduced by 27% while the non-injury crashes were reduced by 21%.

A rapid assessment method was applied to determine the energy efficiency and illuminance of a street lighting installation using a mobile measurement system (Tomczuk et al., 2021). The assessment method was based on simultaneous measurement of illuminance from three lux meters placed on the roof of a vehicle that was moving with the traffic flow. Based on the collected measurement data, with the use of terrain maps, geographic information system (GIS) data and installation design documentation, it would be possible to determine the parameters of energy efficiency indicators for a selected section of roadway.

Buyukkinaci et al. (2019) examined the visibility levels on a test road in relationship with the traffic flow speed and traffic volume. The study showed that when the vehicle speed is constant at the current speed limits for urban roads, the visibility level values remain within the acceptable limits and changing the luminous fluxes will not significantly change the visual performance of the drivers up to two lower lighting classes. The lighting classes are defined by the average luminance (Lav) values under given color temperatures (Buyukkinaci et al., 2018). For instance, for a 4,000 K color temperature luminaire, the four lighting classes from high to low are Lav≥1.5 cd/m^2, Lav≥1.0 cd/m^2, Lav≥0.75 cd/m^2, and Lav≥0.5 cd/m^2. The study also found that the light level can be reduced to create two additional classes besides the current one when the traffic density decreases at the times when vehicle speeds do not decrease.

The literature review did not find any publications that address design, construction, or utilization of roadway lighting test beds. Therefore, the lighting test beds constructed through this study would establish a pioneering facility for testing, evaluating, and analyzing roadway light luminaires.

1.3 Main Tasks

The following tasks were accomplished in this study.

Identified the test bed functions according to INDOT lighting design parameters and luminaire applications and selected the sites to build the lighting test beds. Designed the lighting test beds with specified number of light poles, spacing between poles, and mounting heights of luminaires. This includes the number of foundations, wiring, conduits, switches to control power to the poles. Different lighting pole configurations and lighting distribution types were considered in the design of the test beds to cover the most popular applications of roadway lighting.

The test bed sites were selected in the areas where the effects of adjacent lighting sources would be minimized. The lighting test beds were constructed at the two selected INDOT sites in accordance with INDOT's standards. Illuminance values of roadway luminaires were measured and analyzed after the construction of the lighting test beds. Remotely controlled cart and drone were used to automate the illuminance measurement process. A user-friendly illuminance data repository was developed to store and display lighting testing data. The building information modeling (BIM) and MicroStation platforms were applied to record and store the measured illuminance data.

2. DESIGN AND CONSTRUCTION OF TEST BEDS

2.1 Design of Test Beds

Two sites were selected to construct the test bed facilities. One site is located on the property of the INDOT Research and Development Office (1205 Montgomery Street, West Lafayette) and the other site is located on the property of the INDOT Indianapolis subdistrict (7105 South Brookville Road, Indianapolis). The two test bed sites are able to provide easy access for INDOT to perform illuminance measurements and evaluations on its own properties without the need for traffic control. The test bed sites are located in the areas where the effects of adjacent lighting sources, which are not part of the roadway lighting, will be minimized, such as lighting from adjacent office buildings and restaurants.

The lighting test beds were designed by INDOT Central Office. Figure 2.1 is the design plan at the West Lafayette site. Three lighting poles were built on the existing friction test road section. The mounting height of the light poles was 25 feet with a 10-foot mast arm. All the lighting poles were to be set at 10 feet from the edge of the pavement. The distance between adjacent lighting poles is 155 feet. In addition, two existing wall mount light fixtures on one of the garage walls were to be used for evaluation of highway underpass luminaires.

Figure 2.2 shows the design plan at the Indianapolis site. Six lighting poles were to be built on the existing road inside the subdistrict property. The mounting height of the light poles was 40 feet with a 10-foot mast arm. All the lighting poles were to be set at 10 feet from the edge of the pavement. The distance between adjacent lighting poles is 275 feet. Two lighting pole mounting heights, 25 feet and 40 feet as shown in Figure 2.3, were designed to evaluate the two most common lighting installations of roadway luminaires.

2.2 Construction of Test Beds

The construction contract was offered to the Hoosier Company, Inc. The construction of the test beds started with foundation excavation on April 12, 2021. The major construction activities include foundation excavation, concrete pouring, cable laying, lighting pole installation, pole luminaire installation, and wall luminaire installation. The construction process is illustrated with photos in Figure 2.4 through Figure 2.9.

After the construction was completed, the Study Advisory Committee (SAC) members conducted inspections at the two light beds sites. The inspection at the West Lafayette site (Figure 2.10) was performed on May 5, 2021. The SAC members inspected the constructed light bed with three light poles along the INDOT Friction Test Pavement and two underpass lights on a garage wall on the INDOT Research and Development facility. It was found that the installation of the lighting testbeds was complete and well done. The only item was that more fill was needed around the handhole. The Hoosier Company was notified and the handhole was properly filled at a later date. The two underpass lights were turned on by light sensing (photocells) when it became dark. The lights on poles were turned on one after another by light sensing (photocells) after dark. All the lights worked well.

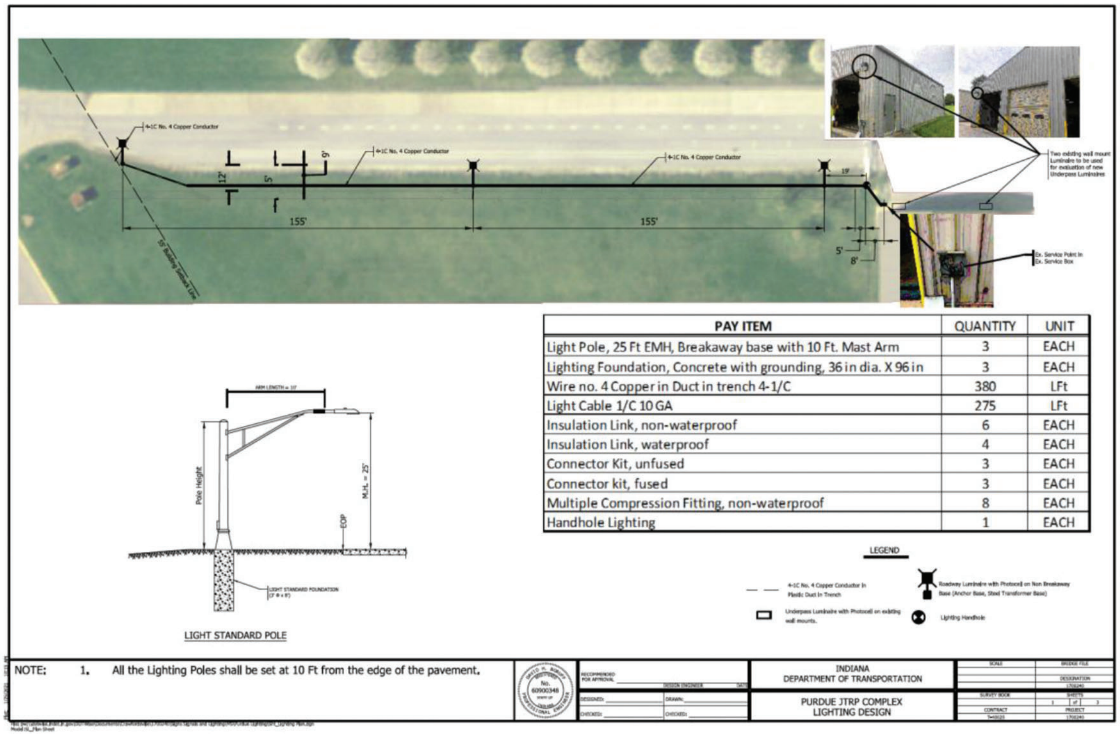


Figure 2.1 Lighting test bed design at the West Lafayette site.

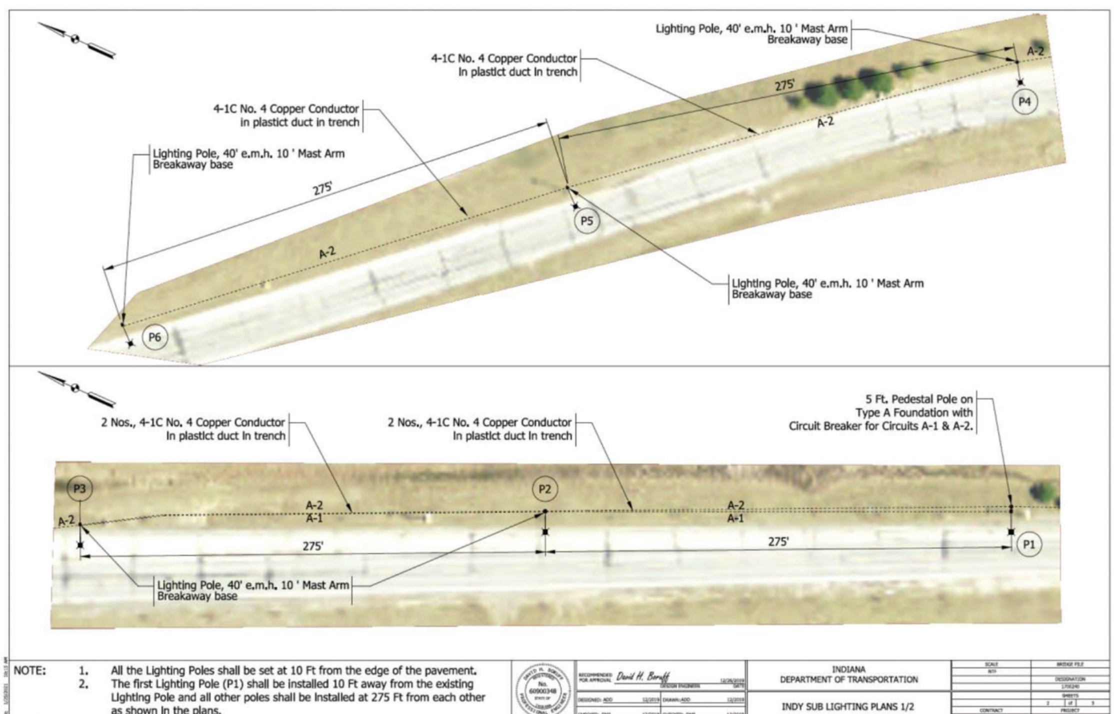
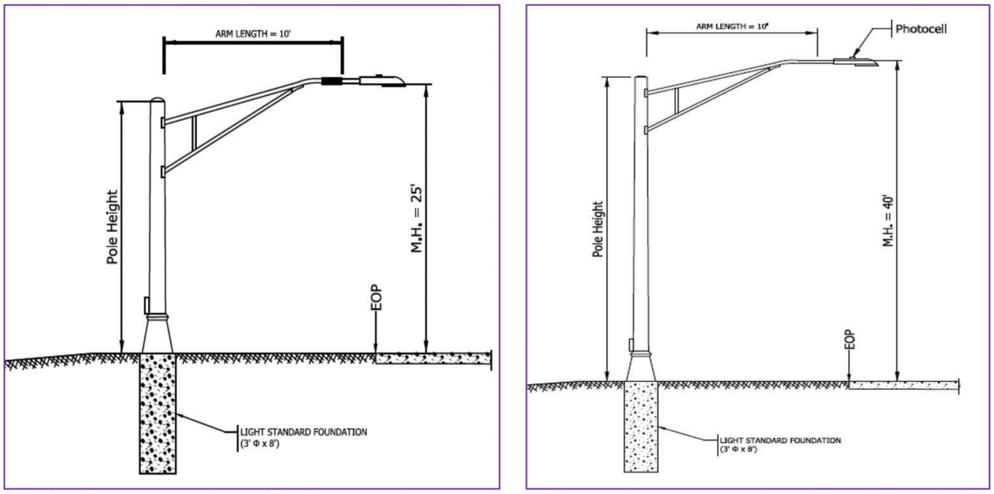


Figure 2.2 Lighting test bed design at the Indianapolis site.

The inspection at the Indianapolis site was performed on June 15, 2021. The SAC members inspected the constructed light bed with six lighting poles (Figure 2.11). The installation of the light bed was complete and well done. The lights on the old poles were switched off and the light bed poles were lighted. All the lights looked good and worked well.



(a) 25-foot mounting height (West Lafayette) (b) 40-foot mounting height (Indianapolis)

Figure 2.3 Lighting pole dimensions.

Figure 2.4 Foundation excavation.

Figure 2.5 Concrete pouring.

Figure 2.6 Cable laying.

Figure 2.7 Lighting pole installation.

Figure 2.8 Pole luminaire installation.

Figure 2.9 Wall luminaire installation.

Figure 2.10 Inspection at the West Lafayette site.

Figure 2.11 Inspection at the Indianapolis site.

3. ILLUMINANCE MEASUREMENT AND ANALYSIS

3.1 Illuminance at the Indianapolis Site

The luminaires on the lighting poles at the Indianapolis site were 250 W high pressure sodium (HPS) light bulbs. The illuminance of the luminaires at the Indianapolis site was measured manually with hand-held illuminance meter on June 13, 2021. The layout of the six lighting poles is shown in Figure 3.1, with Pole #1 to Pole #6 from right to left.

The grids (red dots in Figure 3.1) for illuminance measurement had 15-foot intervals in the longitudinal direction along the road and 3-foot intervals in the transverse direction from the pavement edge. The measured illuminance values in ft-cd at the grid points in both the longitudinal and transverse directions are presented in Tables 3.1, 3.2, 3.3, 3.4, and 3.5. Each of the six tables presents the illuminance values around one particular pole.

In order to visually illustrate the illuminance distributions related to the lighting poles, the measured illuminance values over the pre-marked grid points are depicted in Figures 3.2, 3.3, and 3.4 in terms of a heatmap. The horizontal axis shows the distances of the grid points from light poles and the vertical axis shows the distances of the grid points from the pavement edge. As displayed, the illuminance gradually decreases as the distance away from the pole increases.

3.2 Illuminance at the West Lafayette Site

The luminaires on the lighting poles and on the garage wall (for evaluating underpass lighting) at the West Lafayette site were 150 W high pressure sodium (HPS) light bulbs. The illuminance of the luminaires at this site was measured manually with hand-held illuminance meter on October 19, 2021. The layout and the measuring grid (red dots) of the lighting poles are shown in Figure 3.5. Similarly, the layout and the measuring grid (red dots) of the garage wall luminaires for roadway underpass lighting are shown in Figure 3.6.

Same as the Indianapolis site, the grids for illuminance measurement had 15-foot intervals in the longitudinal direction along the road and 3-foot intervals in the transverse direction from the pavement edge. The measured illuminance values along the lighting poles in ft-cd at the grid points in both the longitudinal and transverse directions are presented in Table 3.6. The heat map of the illuminance values is displayed in Figure 3.7. The horizontal axis shows the distances of the grid points from light poles and the vertical axis shows the distances of the grid points from the pavement edge. As can be seen in the heatmap, the areas close to the light poles have high illuminance levels with dark colors and the areas in the middle between light poles have low illuminance levels with light colors.

The measured illuminance values of the garage wall luminaires for underpass lighting are listed in Table 3.7 and the corresponding heat map is exhibited in Figure 3.8. As can be seen in the heatmap, the areas close to the wall luminaires have high illuminance levels with dark colors. However, for some unknown reasons, Wall Luminaire #2 had higher illuminance than Wall Luminaire #1 even though the two luminaires were both new and were installed at the same time.

3.3 Automation of Illuminance Measurement

The illuminance measurements are conducted manually in Indiana. However, manually illuminance measuring at a large number of specified grid points is tedious and labor-intensive. Mobile illuminance measurement methods have been evaluated and utilized to increase the efficiency and reduce labor intensity (Jaśkowski & Tomczuk, 2019; Novotný, 2015; Tomczuk et al., 2021). To explore the feasibility of automation of illuminance measurement, the illuminance at the West Lafayette site was measured with a remote-control electrical cart and a drone. Figure 3.9 shows the three devices utilized in the measurements. The three devices include the following: illuminance meter (General Tools DLM112SD)—the meter can

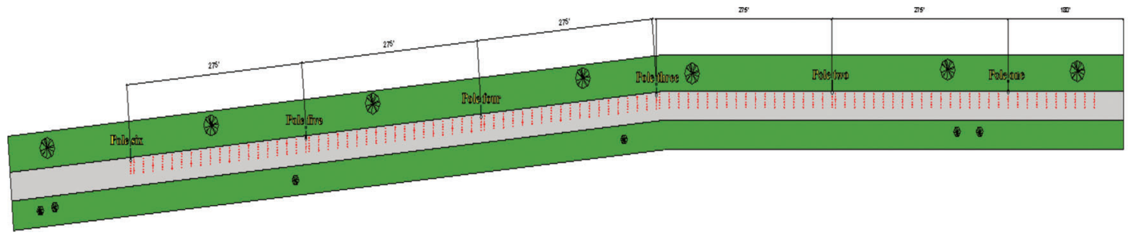


Figure 3.1 Layout of lighting poles at the Indianapolis site.

TABLE 3.1
Illuminance Near Pole #1 at the Indianapolis Site

	Distance from Pole	Illuminance (ft-cd)			
		3′ from Pavement Edge	6′ from Pavement Edge	9′ from Pavement Edge	12′ from Pavement Edge
—	135′	0.08	0.08	0.08	0.09
	120′	0.1	0.1	0.11	0.12
	105′	0.15	0.16	0.17	0.2
	90′	0.25	0.26	0.28	0.3
	75′	0.35	0.38	0.4	0.45
	60′	0.49	0.53	0.61	0.67
	45′	0.86	0.97	1.06	1.08
	30′	1.47	1.56	1.67	1.57
	15′	2.35	2.34	2.29	2.09
Toward Pole #2	Pole #1	2.27	2.18	1.96	1.71
	15′	2.35	2.35	2.27	2.02
	30′	1.59	1.62	1.6	1.46
	45′	0.77	0.86	0.91	0.94
	60′	0.46	0.52	0.61	0.64
	75′	0.34	0.35	0.39	0.41
	90′	0.23	0.25	0.26	0.28
	105′	0.24	0.25	0.26	0.27
	120′	0.18	0.15	0.18	0.18
	135′	0.11	0.11	0.13	0.13

measure illuminance automatically with adjustable time intervals from 1 second to 1 hour. Remote control electrical cart (Yahboom Professional 6WD Robot Car)—the cart can be remotely controlled through a WiFi or Bluetooth connected mobile phone. Drone (the DJI Mavic 2 Zoom)—the drone can carry an object up to 900 grams when flying.

3.3.1 First Measurement

As indicated previously, the illuminance of the luminaires at the West Lafayette site was measured manually with hand-held illuminance meter on October 19, 2021. The measurements with the cart and drone were conducted on the following two days, October 20th and 21st, after the manual measurement. During the measurement, the pavement was dry and clean, and the weather was clear and calm. The illuminance measurement started approximately 15 minutes sunset each night. Figure 3.10 displays the photos of the three different ways of the illuminance measurements. Two people were involved for each of the three ways of illuminance measurements.

For the measurement with the cart, the illuminance meter was attached to the cart and the meter was set to automatically read illuminance values at 1-second intervals. As the cart moved forward, the illuminance meter could read and store the illuminance values continuously. The measurement using the drone was conducted in a similar manner to using the cart. That is, the attached illuminance meter would read and store the illuminance values at 1-second intervals as the drone flew forward. One reason for utilizing a drone as the carrier for roadway lighting illuminance measurement is that it can measure illuminance at multiple altitudes. The illuminance values were measured at three heights—1.26 meters, 1.74 meters, and 2.86 meters from the pavement. It was desired to fly the drone at a very low height so that the illuminance on the pavement could be measured. However, the minimum flight height was limited to 1.0 meter because when the flight height was less than 1.0 meter the drone would detect the pavement surface as an obstacle and would then activate its anti-collision function. The illuminance was measured at the three heights to examine the lighting intensities at different vertical

TABLE 3.2
Illuminance Near Pole #2 at the Indianapolis Site

	Distance from Pole	Illuminance (ft-cd)					
		3′ from Pavement Edge	6′ from Pavement Edge	9′ from Pavement Edge	12′ from Pavement Edge	15′ from Pavement Edge	18′ from Pavement Edge
—	150′	0.07	0.08	0.08	0.08	0.09	0.09
	165′	0.1	0.1	0.1	0.1	0.11	0.11
	180′	0.16	0.15	0.16	0.16	0.16	0.17
	195′	0.22	0.24	0.25	0.25	0.25	0.28
	210′	0.34	0.36	0.37	0.38	0.4	0.43
	225′	0.46	0.5	0.53	0.58	0.62	0.64
	240′	0.82	0.82	0.85	0.95	1	1.02
	255′	1.39	1.4	1.5	1.63	1.6	1.44
	270′	2.37	2.37	2.3	2.3	2.06	1.69
Toward Pole #3	Pole #2	2.44	2.4	2.3	2.15	1.86	1.54
	15′	2.37	2.31	2.35	2.29	2.17	1.78
	30′	1.2	1.37	1.38	1.44	1.36	1.11
	45′	0.62	0.69	0.77	0.81	0.96	0.8
	60′	0.37	0.45	0.46	0.49	0.45	0.42
	75′	0.23	0.27	0.28	0.3	0.29	0.28
	90′	0.17	0.19	0.17	0.22	0.21	0.22
	105′	0.13	0.12	0.15	0.14	0.18	0.17
	120′	0.08	0.09	0.1	0.11	0.12	0.12
	135′	0.08	0.08	0.09	0.1	0.11	0.11
	150′	0.11	0.12	0.14	0.17	0.18	0.2

TABLE 3.3
Illuminance Near Pole #3 at the Indianapolis Site

	Distance from Pole	Illuminance (ft-cd)					
		3′ from Pavement Edge	6′ from Pavement Edge	9′ from Pavement Edge	12′ from Pavement Edge	15′ from Pavement Edge	18′ from Pavement Edge
—	165′	0.32	0.42	0.51	0.56	0.55	0.51
	180′	0.65	0.87	0.93	0.93	0.88	0.73
	195′	1.21	1.4	1.48	1.52	1.39	1.13
	210′	1.51	1.49	1.52	1.68	1.8	1.23
	225′	1.69	1.82	1.93	1.93	1.64	1.25
	240′	1.72	1.95	1.98	1.98	1.8	1.3
	255′	2.65	3.03	3.27	3.75	3.06	1.96
	270′	2.8	3.37	3.17	2.78	2.37	1.8
Toward Pole #4	Pole #3	2.55	3.07	2.73	2.47	2.26	1.74
	15′	2.07	2.69	2.85	2.98	3.01	1.95
	30′	1.07	1.12	1.16	1.29	1.32	1.12
	45′	0.64	0.79	0.85	0.84	0.82	0.81
	60′	0.66	0.57	0.64	0.65	0.61	0.63
	75′	0.23	0.31	0.4	0.48	0.54	0.55
	90′	0.14	0.22	0.29	0.34	0.37	0.42
	105′	0.09	0.16	0.2	0.24	0.29	0.31

levels. The flying speed of the drone was 1.0 meter per second.

The total measurement times for the three methods are shown in Table 3.8 along with their respective labor intensities in terms of person-hours. The labor intensities are plotted in Figure 3.11 for comparison of the labor intensities of the three methods. Since the use of cart and drone was a new experience, some time was spent on adjusting the control and operations of the devices as a learning process during the measurements. As illustrated in Figure 3.11, the labor intensity of the drone measurement decreased from 0.98 to 0.77 and then to 0.50 as the operators got more familiar with the operation process after each run of the measurement. Both Table 3.8 and Figure 3.11 clearly indicate that the two automated methods considerably improved the

TABLE 3.4
Illuminance Near Pole #4 at the Indianapolis Site

	Distance from Pole	Illuminance (ft-cd) 3′ from Pavement Edge	6′ from Pavement Edge	9′ from Pavement Edge	12′ from Pavement Edge
—	120′	0.15	0.2	0.22	0.24
	135′	0.1	0.13	0.16	0.19
	150′	0.12	0.17	0.22	0.26
	165′	0.16	0.21	0.26	0.23
	180′	0.21	0.26	0.3	0.32
	195′	0.29	0.37	0.48	0.46
	210′	0.58	0.66	0.7	0.71
	225′	0.84	0.92	0.88	0.83
	240′	1.09	1.11	1.14	0.2
	255′	1.36	1.51	1.66	1.53
	270′	2.3	2.4	2.2	2.2
Toward Pole #5	Pole #4	2.25	2.27	2.39	2.3
	15′	1.1	1.2	1.27	1.3
	30′	0.88	0.91	0.92	0.94
	45′	0.58	0.62	0.64	0.61
	60′	0.45	0.48	0.5	0.51
	75′	0.28	0.36	0.36	0.37
	90′	0.2	0.2	0.24	0.26
	105′	0.2	0.2	0.24	0.26
	120′	0.13	0.16	0.15	0.2

TABLE 3.5
Illuminance Near Pole #5 at the Indianapolis Site

	Distance from Pole	Illuminance (ft-cd) 3′ from Pavement Edge	6′ from Pavement Edge	9′ from Pavement Edge	12′ from Pavement Edge
—	135′	0.11	0.13	0.14	0.16
	150′	0.09	0.1	0.11	0.13
	165′	0.07	0.9	0.1	0.15
	180′	0.06	0.08	0.09	0.11
	195′	0.07	0.08	0.1	0.12
	210′	0.08	0.1	0.13	0.16
	225′	0.11	0.14	0.16	0.2
	240′	0.24	0.29	0.32	0.38
	255′	0.51	0.56	0.65	0.62
	270′	0.76	0.81	0.87	0.86
	275′	1.18	1.18	1.22	1.31
Toward Pole #5	Pole #5	2.04	2.31	2.31	2.28
	15′	1.67	1.77	1.77	1.58
	30′	0.92	0.98	1	1.01
	45′	0.6	0.61	0.63	0.61
	60′	0.38	0.41	0.43	0.45
	75′	0.29	0.32	0.32	0.33
	90′	0.16	0.2	0.23	0.24
	105′	0.08	0.1	0.12	0.13
	120′	0.06	0.07	0.08	0.1
	135′	0.05	0.06	0.07	0.08

efficiency of illuminance measurement in comparison with the manual method. It should be pointed out that the number of persons for both cart and drone methods can be reduced to one person after gaining experience, which will further improve the efficiency of the automated measurements. The main problems encountered for the automated measurements include the following.

- The cart was not powerful because it moved slowly and could not move in a straight line at some locations.

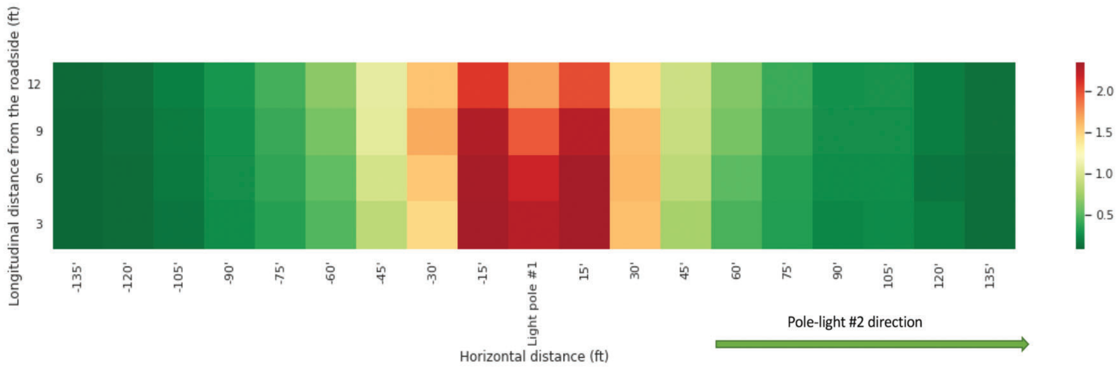


Figure 3.2 Illuminance heat map near Pole #1 at the Indianapolis site.

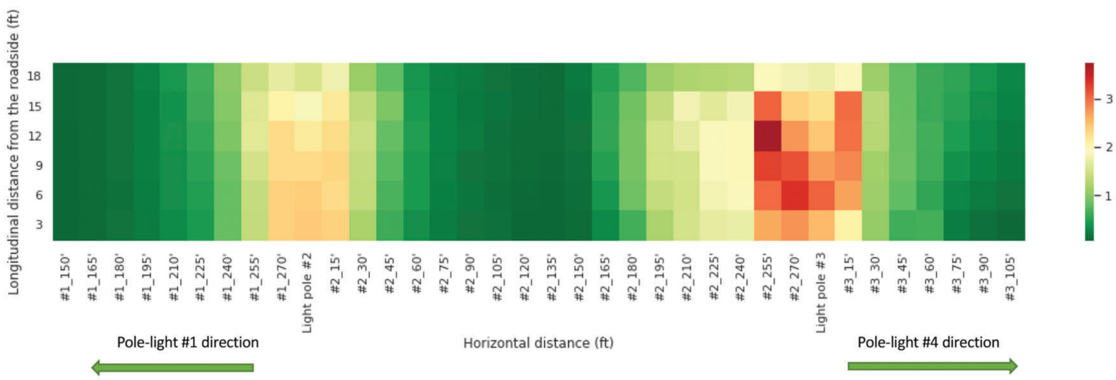


Figure 3.3 Illuminance heat map around Pole #2 and Pole #3 at the Indianapolis site.

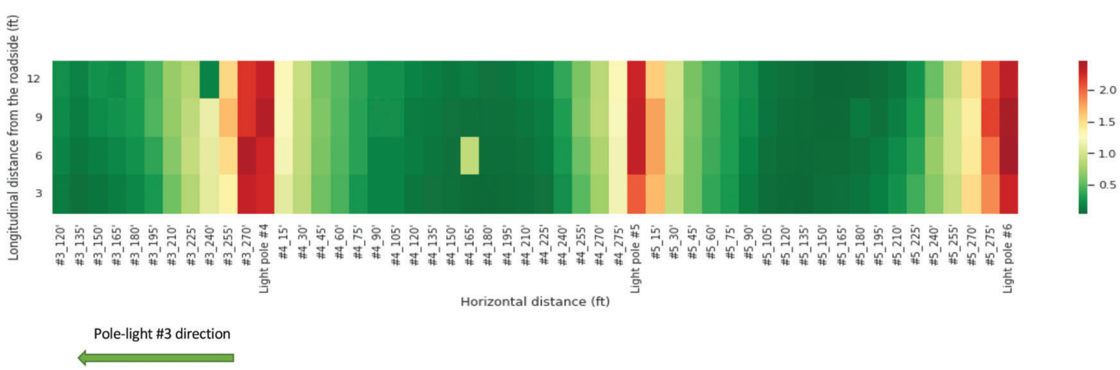


Figure 3.4 Illuminance heat map around Pole #4, Pole #5, and Pole #6 at the Indianapolis site.

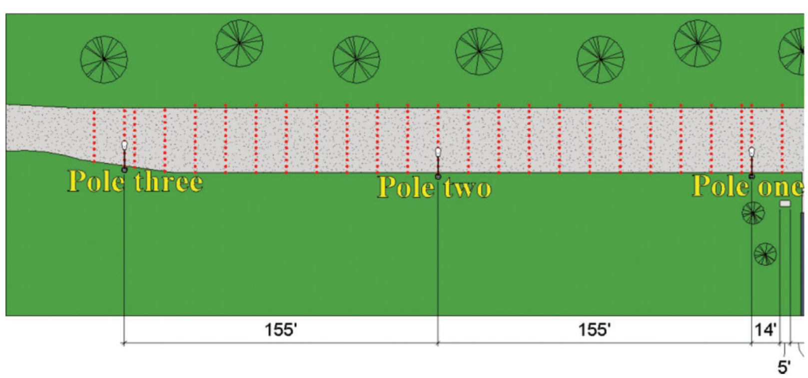


Figure 3.5 Layout and measuring grids of lighting poles.

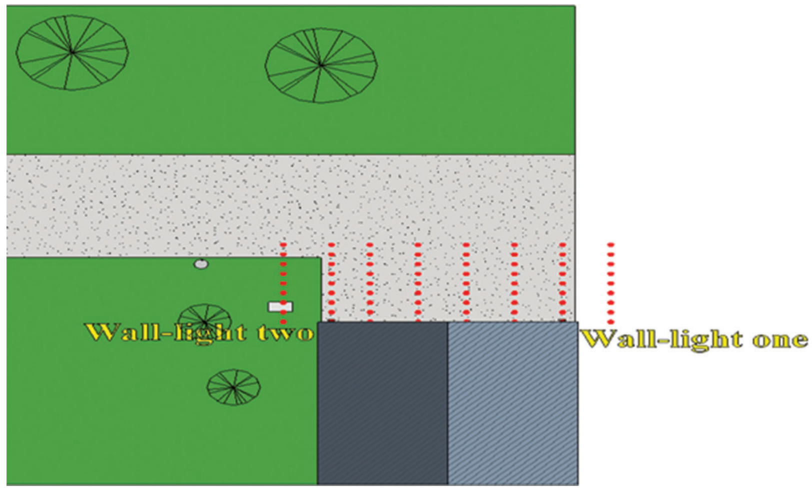


Figure 3.6 Layout and measuring grids of garage wall luminaires.

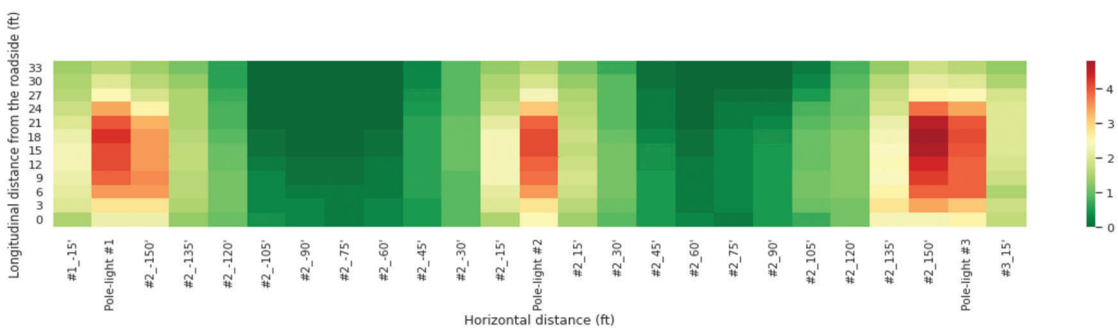


Figure 3.7 Illuminance heat map at the West Lafayette site.

TABLE 3.6
Illuminance at the West Lafayette Site

	Illuminance (ft-cd)											
Distance from Pole	**0′ from Pavement Edge**	**3′ from Pavement Edge**	**6′ from Pavement Edge**	**9′ from Pavement Edge**	**12′ from Pavement Edge**	**15′ from Pavement Edge**	**18′ from Pavement Edge**	**21′ from Pavement Edge**	**24′ from Pavement Edge**	**27′ from Pavement Edge**	**30′ from Pavement Edge**	**33′ from Pavement Edge**
15′	1.4	1.5	1.6	1.8	2	2.2	2.3	2.3	2.2	2.1	2	1.5
Pole #1	1.6	2	2.5	3.4	4	4.3	4.1	4.1	3.9	3.5	2.8	2.2
150′	1.4	1.6	1.9	2.6	3.3	3.5	3.5	3.5	3.6	3.5	2.8	2.2
135′	1.1	1.3	1.5	1.5	1.5	1.6	1.7	1.7	1.6	1.6	1.5	1.3
120′	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.1	1.1	1
105′	0	0	0	0	0	0.1	0.1	0.2	0.3	0.3	0.3	0.4
90′	0	0	0	0	0	0	0	0.1	0.1	0.2	0.3	0.3
75′	0	0	0	0	0	0	0	0.1	0.1	0.2	0.2	0.2
60′	0	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.3	0.3
45′	0.3	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
30′	0.9	0.9	0.9	0.9	1	1	1	1	0.9	0.9	0.9	0.9
15′	1.3	1.5	1.6	1.8	2.1	2.3	2.3	2.3	2.3	2.1	2	1.5
Pole #2	1.6	1.9	2.3	3.1	3.9	4.1	4.1	3.9	3.8	3.5	2.8	2.5
15′	1.1	1.3	1.5	1.6	1.7	1.8	1.7	1.8	1.9	1.8	1.6	1.4
30′	0.7	0.9	0.9	0.9	0.9	1	1.1	1.1	1.1	1.1	1	0.9
45′	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.5
60′	0	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.2	0.3
75′	0	0	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.2
90′	0	0	0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5
105′	0.2	0.3	0.5	0.8	0.9	1	1	1	1.1	1.1	1	0.7
120′	0.8	0.9	1	1	1.1	1.2	1.2	1.2	1.2	1.2	1.1	1.1
135′	1.3	1.6	1.8	1.9	2.2	2.3	2.4	2.5	2.4	2.6	2.8	2.3
150′	1.8	2.1	2.6	3.8	4.6	4.8	4.7	4.4	4.2	3.9	3.4	2.3
Pole #3	1.6	2	2.5	3.4	4	4.1	4	3.9	3.9	3.9	3.1	2.6
15′	1.3	1.5	1.9	2	2	2	2	1.9	1.8	1.5	1.8	1.7

TABLE 3.7
Illuminance of Garage Wall Luminaires at the West Lafayette Site

Distance from Wall	Illuminance (ft-cd)									
	0′ from Garage Wall	3′ from Garage Wall	6′ from Garage Wall	9′ from Garage Wall	12′ from Garage Wall	15′ from Garage Wall	18′ from Garage Wall	21′ from Garage Wall	24′ from Garage Wall	27′ from Garage Wall
10′	0	0.6	0.3	0.4	0.5	0.5	0.4	0.3	0.2	0.2
Light #1	0.3	1.4	1.4	1.6	1.7	1.5	1.2	1	0.7	0.5
10′	0	0.4	0.3	0.5	0.6	0.6	0.5	0.5	0.4	0.3
20′	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
30′	0	0	0.5	0.3	0.3	0.4	0.4	0.5	0.6	0.7
40′	0.2	1.6	1.8	2.2	2.4	2.4	2.4	2.3	2	1.9
Light #2	0.4	3.1	3.1	4	4.5	4.4	4.1	4.4	3.2	2.6
10′	0.1	0.9	0.9	1	1	1.7	1.5	1.4	1.9	1.6

TABLE 3.8
Labor Intensity of Measuring Methods (First Measurement)

Measuring Method	Measuring Time (hour)	Number of Operators	Labor Intensity (person-hours)
Manual	1.330	2	2.660
Cart	0.304	2	0.608
Drone (1.26 m)	0.490	2	0.980
Drone (1.74 m)	0.383	2	0.766
Drone (2.86 m)	0.250	2	0.500
Drone Averaged	0.374	2	0.750

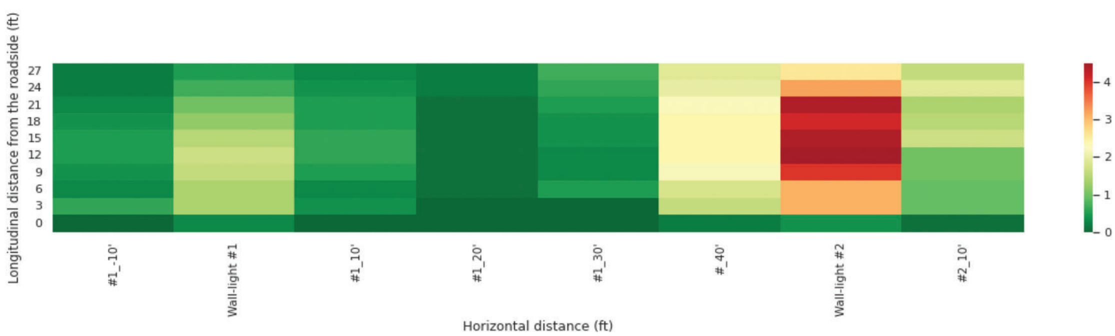


Figure 3.8 Illuminance heat map of garage wall luminaires at the West Lafayette site.

(a) Illuminance meter (b) Remote control cart (c) Drone

Figure 3.9 Illuminance measurement devices.

Figure 3.10 Manual (left), cart (middle), and drone (right) illuminance measurements.

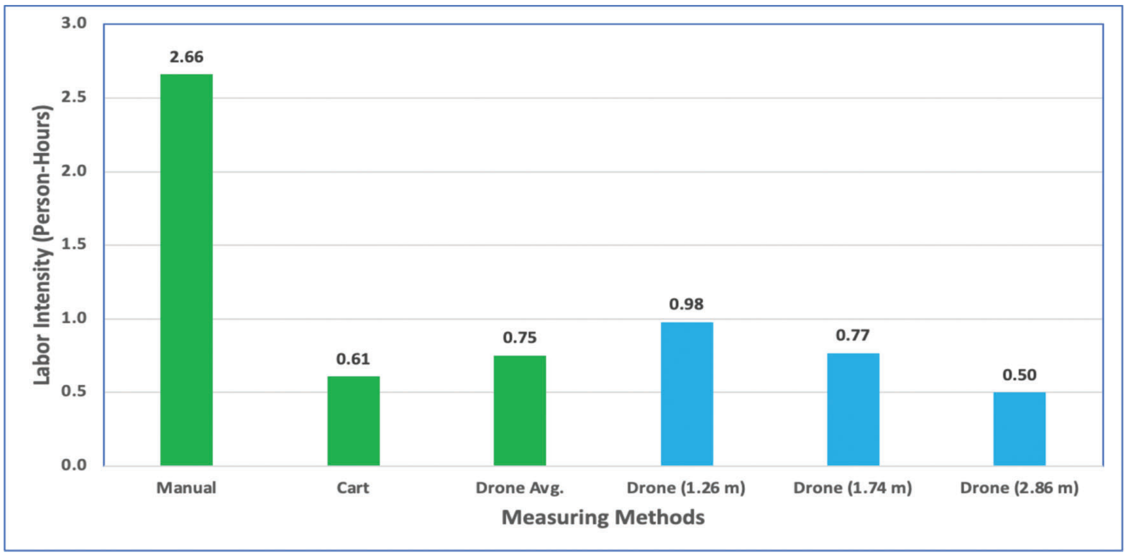


Figure 3.11 Comparison of labor intensities.

- A more powerful cart should be used.
- The battery of the drone could only last less than 30 minutes.
- Backup batteries are necessary.

The drone could not fly below 1.0-meter high and the illuminance on the pavement could not be directly measured.

In order to compare the illuminance values measured with different methods, the illuminance values along the line directly below the three luminaires are shown in Figure 3.12. Since the illuminance on the pavement surface could not be measured, the drone measured illuminance values at the lowest height (1.26 m) are used in Figure 3.12. Although the illuminance values are generally close among the three methods, the manually measured values are mostly higher. The reason for this is not known yet. It may be necessary to conduct more measurements and analyses to reveal the causes.

The use of the drone provides a unique ability to measure and analyze the illuminance levels at different heights or different distances from the luminaires. Figure 3.13 exhibits the illuminance values of the three heights along the line directly below the luminaires. It is interesting to see that the three curves merged when the grid points were horizontally far away from the light poles. The differences in illuminance values are the greatest under the light poles.

3.3.2 Second Measurement

In order to further analyze the automated illuminance measurement, the illuminance was measured again with the three methods (manual, cart, and drone) at the West Lafayette site on April 21 and 22, 2022. The heat maps of manually measured illuminance values are illustrated in Figure 3.14 and Figure 3.15 for the lighting pole luminaires and wall luminaires, respectively. Compared with heat maps in October 2021, the distribution patterns are fairly similar in April 2022. The illuminance values along the line directly below the three luminaires are show in Figure 3.16.

The total measurement times for the three methods are shown in Table 3.9 along with their respective labor intensities in terms of person-hours. In addition, the labor intensities in October 2021 and the differences in the labor intensities of the two times are also included in Table 3.9. The manual labor intensities remain the same. The difference in drone labor intensities is 0.35,

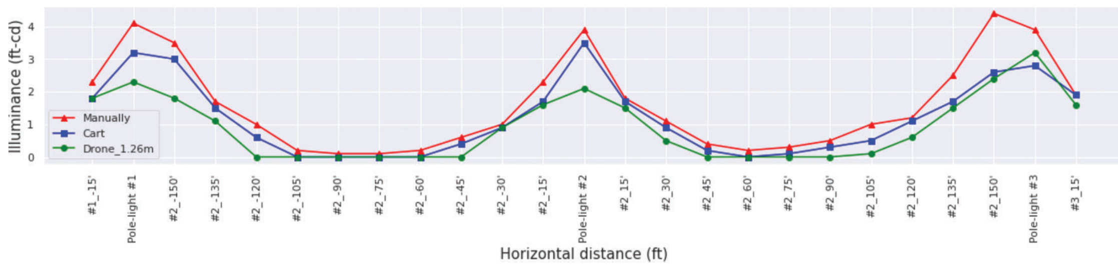


Figure 3.12 Illuminance values of manual and automated measurements.

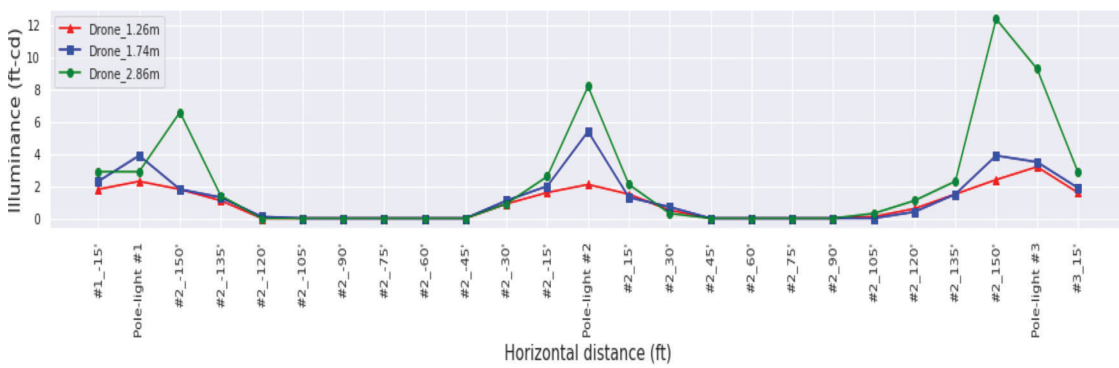


Figure 3.13 Illuminance measured at different heights.

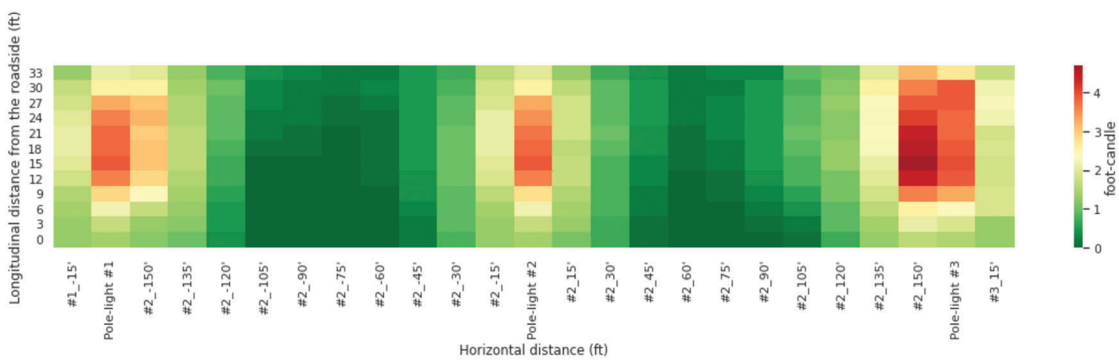


Figure 3.14 Illuminance heat map (measured on April 21, 2022).

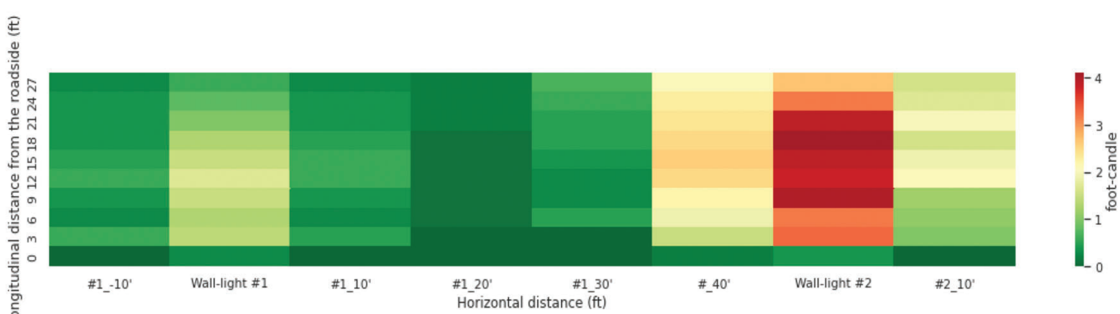


Figure 3.15 Illuminance heat map of garage wall luminaires (measured on April 21, 2022).

indicating that gained experience of the operators further improved the measurement efficiency. However, the labor intensity of cart measurement increased from 0.61 in 2021 to 0.98 in 2022. In fact, this was caused by the insufficient power of the remote-controlled cart as the cart had frequent stops during

TABLE 3.9
Labor Intensity of Measuring Methods (Second Measurement)

Measuring Method	Measuring Time (hour)	Number of Operators	Labor Intensity (person-hour) April 2021 (A)	Labor Intensity (person-hour) October 2021 (B)	Difference (B-A)
Manual	1.33	2	2.66	2.66	0.00
Cart	0.49	2	0.98	0.61	-0.37
Drone	0.20	2	0.40	0.75	0.35

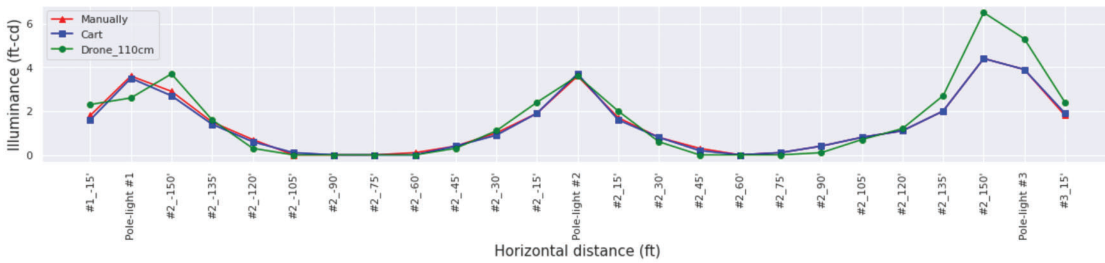


Figure 3.16 Illuminance values of manual and automated measurements (April 2022).

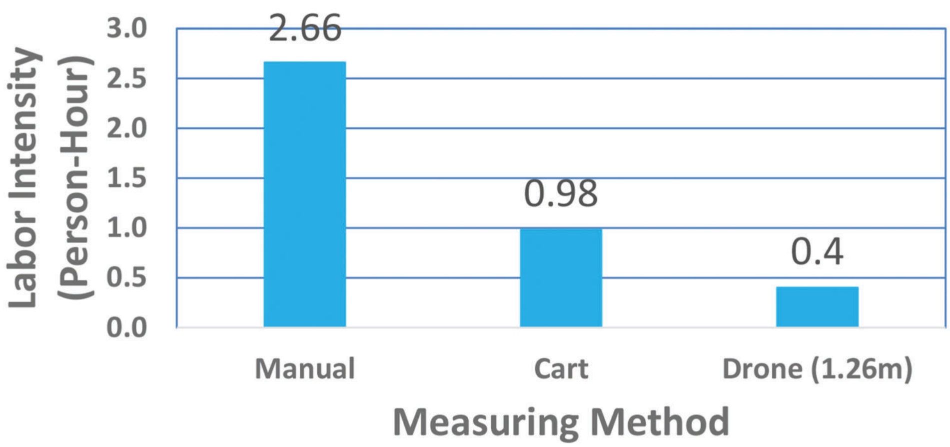


Figure 3.17 Comparison of labor intensities (April 2022).

the measurement. The labor intensities are plotted in Figure 3.17 for comparison of the labor intensities of the three methods.

It is shown through this study that the automated measurements with the cart and the drone can greatly improve the efficiency of roadway illuminance measurements. The experience through this study indicates that the efficiency can be further improved with one-person operation of the cart and drone. To assure smooth measurement, it is recommended that a more powerful electrical cart be used and that backup batteries be equipped for drone operations. The vertical distribution of illuminance values can be further studied with drone-measured illuminance at different heights.

3.4 Simulation of Luminaire Illuminance

A lighting simulation was performed using AGi32 software (Speer, 2021). AGi32 is a simulation tool used for designing lighting projects and calculating the amount of light that will be delivered based on user-set parameters. With manufacturer-provided luminaire parameters, 109 illuminance values of pole luminaires at the West Lafayette site were calculated with AGi32 as shown in Figure 3.18.

The AGi32 calculated values were based on the manufacturer's luminaire parameter without any light losses. Thus, the calculated illuminance values were assumed to be for new luminaires. To compare the simulated illuminance with the measured illuminance, the heat maps of the simulated values and the measured values in 2021 are plotted in Figure 3.19 and Figure 3.20, respectively.

As the colors shown, the AGi32 generated values are much higher than those measured manually. To examine the change of illuminance, different light loss factors were included in the AGi32 input to simulate the light levels. A light loss factor is the depreciating

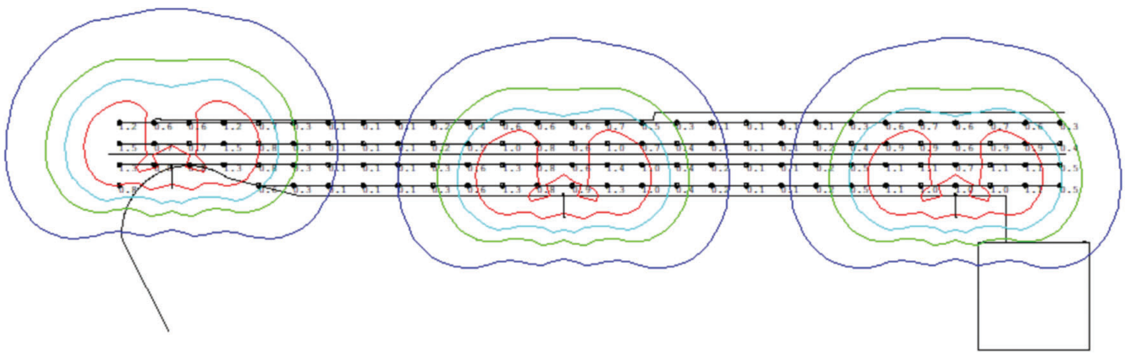


Figure 3.18 AGi32 generated illuminance values.

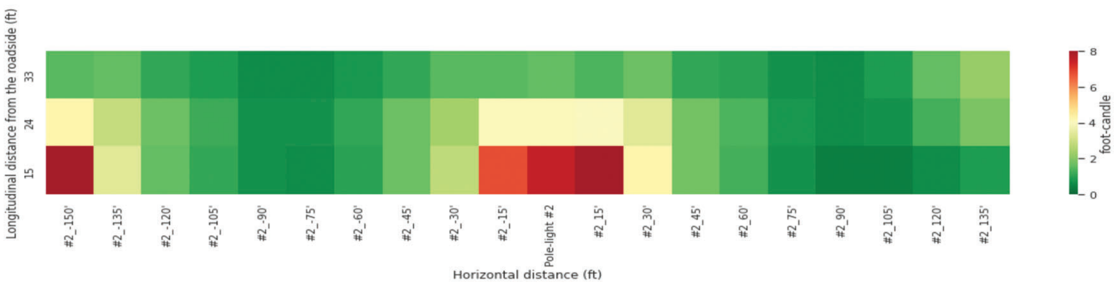


Figure 3.19 Heat map of AGi32 generated illuminance.

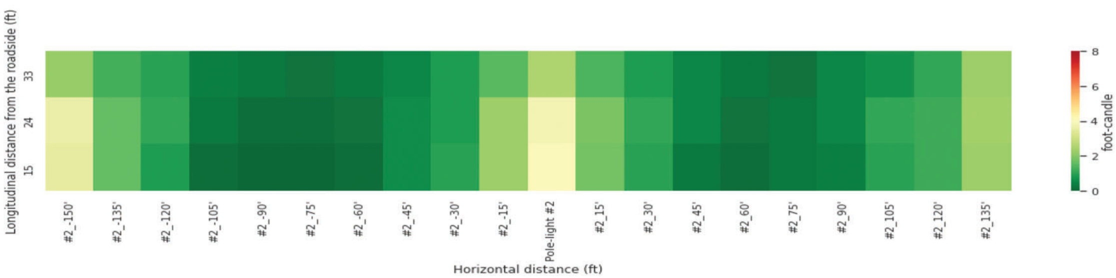


Figure 3.20 Heat map of manually measured illuminance (October 2021).

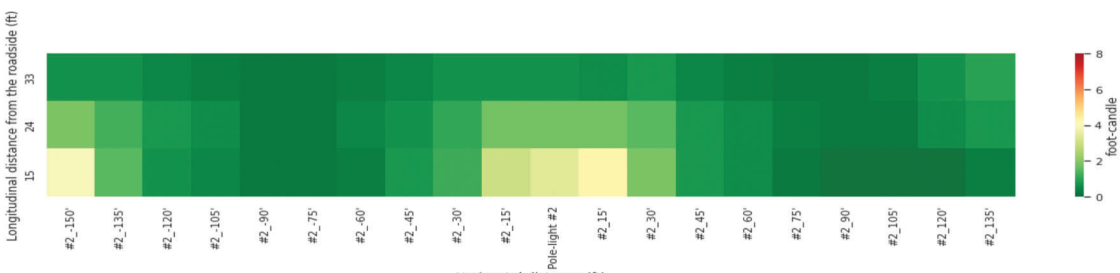


Figure 3.21 AGi32 generated heat map with a light loss factor of 0.45.

light output at certain point in time in the future compared to initial light output. It was found that using a light loss factor of 0.45 would result in a heat map (Figure 3.21) that is similar to the one measured in October 2021. This indicates that the light output of the luminaires in October 2021 was 45% of the initial light output of the luminaires when they were new in May 2021. However, the light output depreciation seems to be too high for only 5 months in service. The comparison between the actual measurement and the AGi32 output implies that it would be necessary to calibrate the AGi32 calculations with the measured illuminance values.

4. DATA REPOSITORY MODEL FOR LIGHTING TEST BEDS

The lighting test beds were built to evaluate new roadway luminaires in a safe and effective manner. It was desired to create a computerized model of the test facility for effective data storage and management. The building information modeling (BIM) and the MicroStation were selected as the platforms to develop the data repository model for managing the operations of the lighting test facility.

4.1 BIM Based Model

The BIM based model contains the attribute information of components, including luminaire parameters and illuminance values. A visual programming tool, Dynamo Software, was used to create the attribute information into the model. The visual programming code to create parameters for luminaries is shown in Figure 4.1. The procedure includes three modules.

1. Import Excel data.
2. Create parameter names.
3. Input parameter values.

The visual displays of the BIM based models are demonstrated in Figure 4.2 and Figure 4.3 for the Indianapolis site and the West Lafayette site, respectively.

The first step of the model was to create the input information related to the luminaires, including manufacturer, type of luminaire, and lamp catalog, as shown in Figure 4.4. In this BIM model, sheets were used to record the measured illuminance values. The code for importing the illuminance values into the model is shown in Figure 4.5. The procedure includes three modules.

1. Import Excel data.
2. Create schedules.
3. Input values.

The feasibility of the model was tested with the illuminance measurements. The data importing process

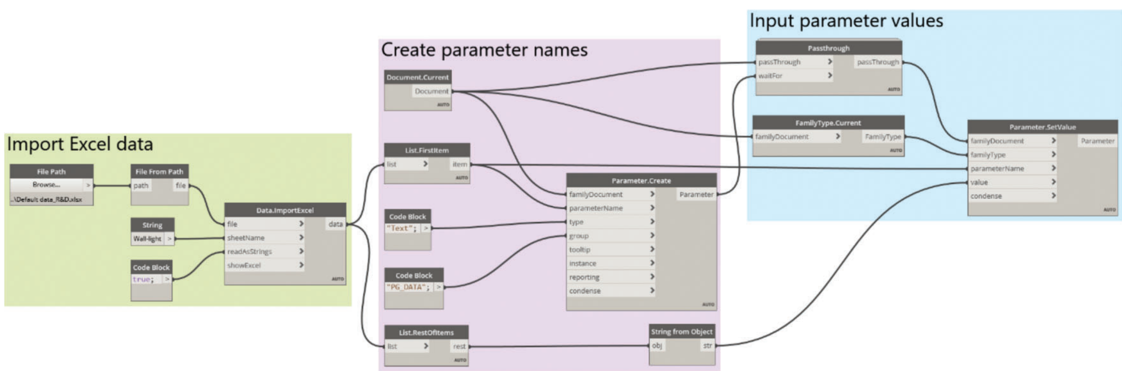


Figure 4.1 Visual programming code.

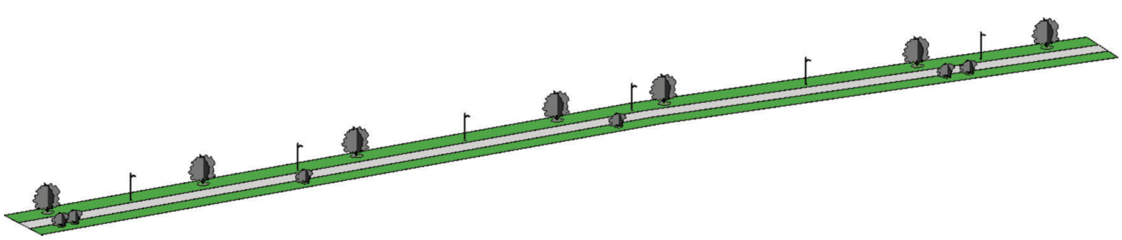


Figure 4.2 Visual display of the BIM-based data repository model for the Indianapolis site.

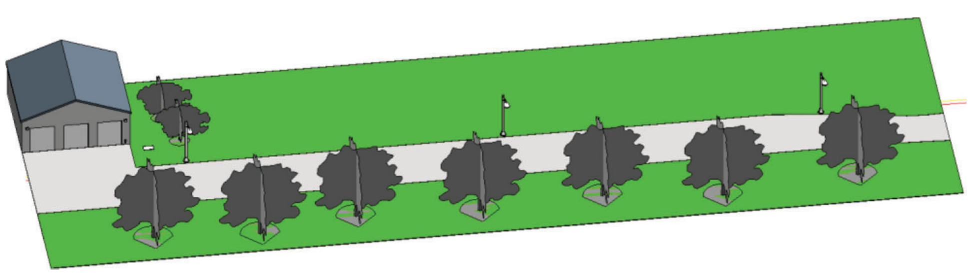


Figure 4.3 Visual display of the BIM-based data repository model for the West Lafayette site.

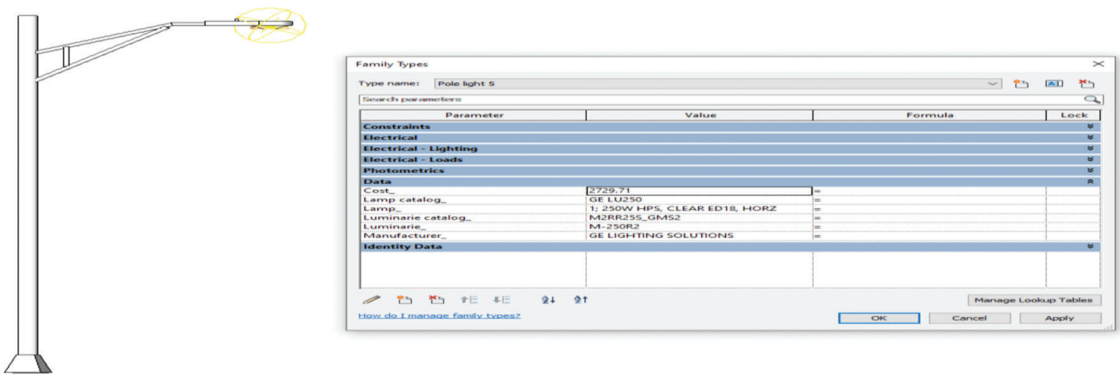


Figure 4.4 Luminaire input.

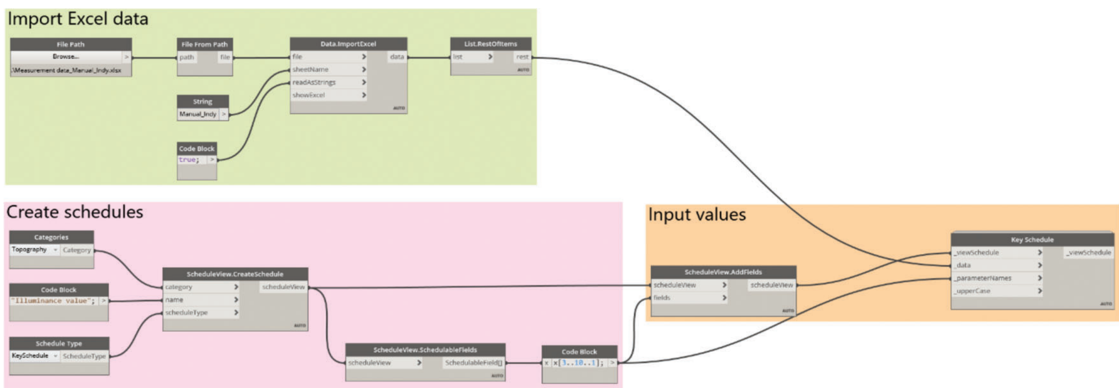


Figure 4.5 Code for importing illuminance values.

<Illuminance value_250W_Manual>

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Light pole	Distance	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd	Light levels in ft-cd
Light Pole #1	15'	1.4	1.5	1.6	1.8	2	2.2	2.3	2.3	2.2	2.1	2	1.5
Light Pole #1	Front	1.6	2	2.5	3.4	4	4.3	4.1	4.1	3.9	3.5	2.8	2.2
Light Pole #2	150'	1.4	1.6	1.9	2.6	3.3	3.5	3.5	3.5	3.6	3.5	2.8	2.2
Light Pole #2	135'	1.1	1.3	1.5	1.5	1.5	1.6	1.7	1.7	1.6	1.6	1.5	1.3
Light Pole #2	120'	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.1	1.1	1
Light Pole #2	105'	0	0	0	0	0	0.1	0.1	0.2	0.3	0.3	0.3	0.4
Light Pole #2	90'	0	0	0	0	0	0	0	0.1	0.1	0.2	0.3	0.3
Light Pole #2	75'	0	0	0	0	0	0	0	0.1	0.1	0.2	0.2	0.2
Light Pole #2	60'	0	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.3	0.3
Light Pole #2	45'	0.3	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
Light Pole #2	30'	0.9	0.9	0.9	0.9	1	1	1	1	0.9	0.9	0.9	0.9
Light Pole #2	15'	1.3	1.5	1.6	1.8	2.1	2.3	2.3	2.3	2.3	2.1	2	1.5
Light Pole #2	Front	1.6	1.9	2.3	3.1	3.9	4.1	4.1	3.9	3.8	3.5	2.8	2.5
Light Pole #2	15'	1.1	1.3	1.5	1.6	1.7	1.8	1.7	1.8	1.9	1.8	1.6	1.4
Light Pole #2	30'	0.7	0.9	0.9	0.9	0.9	1	1.1	1.1	1.1	1.1	1	0.9
Light Pole #2	45'	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.5
Light Pole #2	60'	0	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.2	0.3
Light Pole #2	75'	0	0	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.2
Light Pole #2	90'	0	0	0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Light Pole #2	105'	0.2	0.3	0.5	0.8	0.9	1	1	1	1.1	1.1	1	0.7
Light Pole #2	120'	0.8	0.9	1	1	1.1	1.2	1.2	1.2	1.2	1.2	1.1	1.1
Light Pole #2	135'	1.3	1.6	1.8	1.9	2.2	2.3	2.4	2.5	2.4	2.6	2.8	2.3
Light Pole #2	150'	1.8	2.1	2.6	3.8	4.6	4.8	4.7	4.4	4.2	3.9	3.4	2.3
Light Pole #3	Front	1.6	2	2.5	3.4	4	4.1	4	3.9	3.9	3.9	3.1	2.6
Light Pole #3	15'	1.3	1.5	1.9	2	2	2	2	1.9	1.8	1.5	1.8	1.7

Figure 4.6 An example of an illuminance sheet.

was fast and smooth. A created illuminance sheet is shown in Figure 4.6.

4.2 MicroStation Model

The illuminance data repository model was also developed on the MicroStation platform because of the common use of MicroStation at INDOT offices. The visual displays of the MicroStation based illuminance data repository model are illustrated in Figures 4.7 and 4.8 for the Indianapolis site and the West Lafayette site, respectively.

Tags are used to store the luminaire parameters in the MicroStation model. The luminaire parameters can be revealed by double clicking the name of the pole-light to open the tag, as shown in Figure 4.9. The illuminance values are saved in Excel files. Links can be used to connect the model with the Excel files. The values can be displayed when the linked file is selected and opened in the model (Figure 4.10).

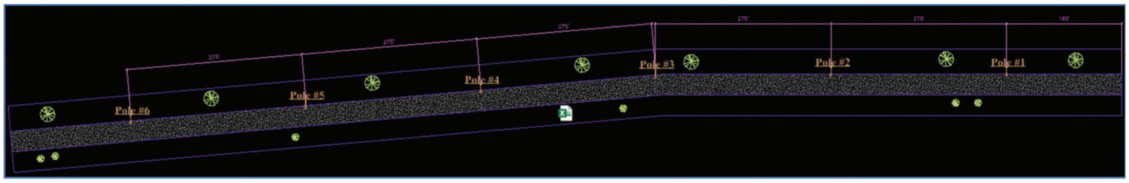


Figure 4.7 MicroStation-based data repository model for the Indianapolis site.

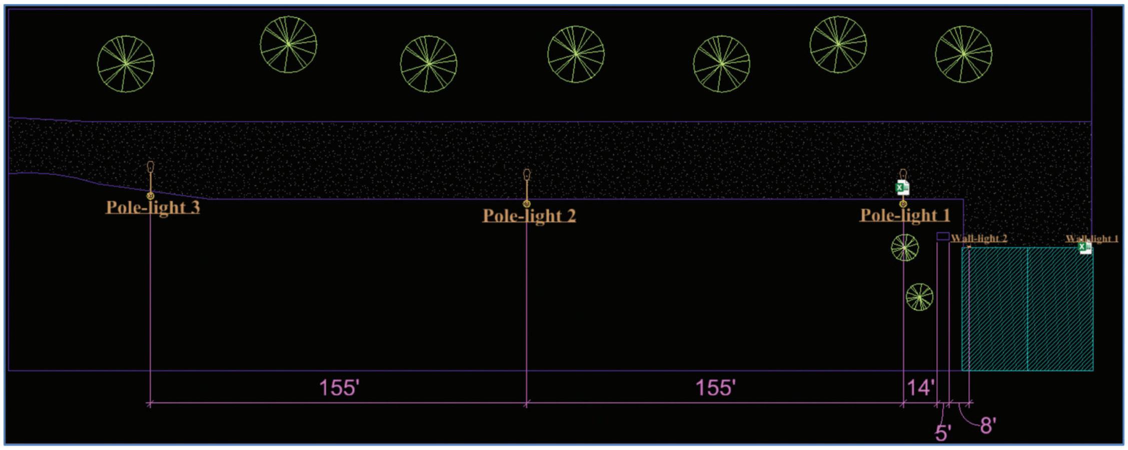


Figure 4.8 MicroStation-based data repository model for the West Lafayette site.

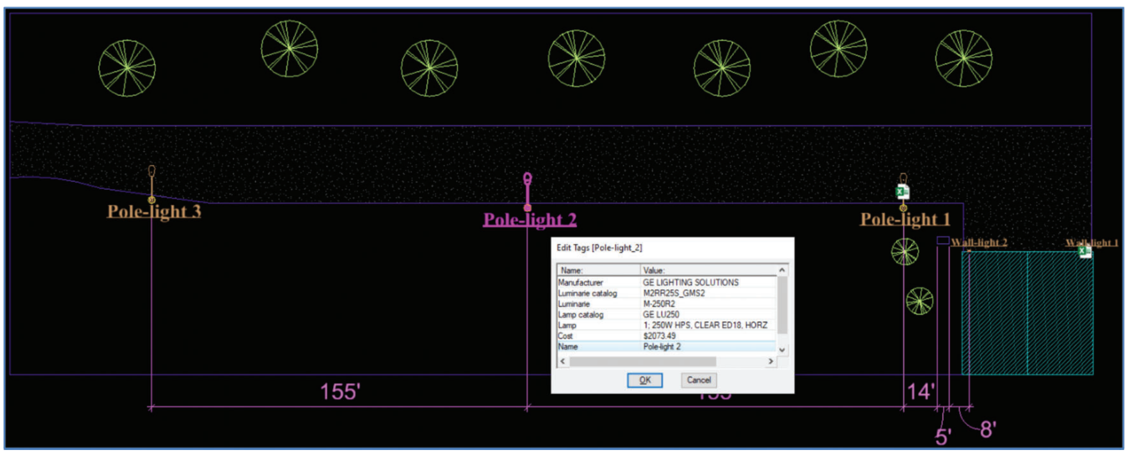


Figure 4.9 Luminaire parameters under tag.

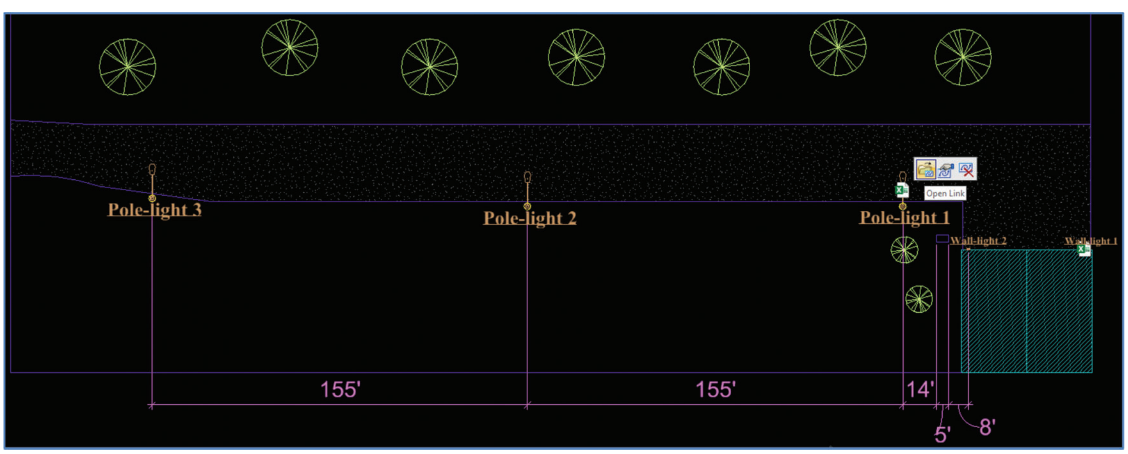


Figure 4.10 Linked Excel file.

5. CONCLUSIONS

Through this study, the lighting test beds were successfully constructed. In order to improve the efficiency and flexibility of illuminance measurement, this study introduced an automation idea for illuminance measurement. A small remote-controlled electrical cart and a drone were utilized as carriers to achieve automated measurement. By comparing the measurement results generated in different ways, it was found the roadside, average, and maximum illuminance obtained by point-to-point measurement and cart auxiliary measurement are almost the same. AGi32 software was involved to simulate light measurement. Through comparison, the discrepancies were minimized between the simulation data and the field measurement data by adjusting the loss of lighting effectiveness. When the efficiency is at a certain level, the simulation results are close to the actual illuminance values. It is suggested that the AGi32 be calibrated using the measured illuminance values in the lighting test beds.

The lighting test beds in the Indianapolis and West Lafayette sites provide INDOT with effective facilities to evaluate new roadway lighting technologies under controlled conditions. The use of the lighting test beds will completely eliminate the need for traffic control when field testing roadway and underpass models. Consequently, also eliminated is the risk of crashes with illuminance measurements adjacent traffic flows.

The efficient of illuminance measurement can be greatly enhanced by utilizing remotely controlled carts and drones. Although a drone cannot measure the illuminance on the pavement surface due to the safety sensor mechanism, it can be used to measure illuminance at different heights so that the light intensities in the vertical direction can be examined and analyzed. That is, the illuminance values can be measured at additional heights rather than the two fixed pole heights, 40 feet at the Indianapolis site, and 25 feet at the West Lafayette site.

The illuminance data repository model is an effective tool that can greatly facilitate data input and storage process. The use of this model will further increase the productivity of illuminance measurement at the lighting test beds.

The results of this study will be ready to implement to realize the improved efficiency and enhanced safety for evaluating new roadway lighting devices.

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On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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