Problem Chosen	2023	Team Control Number
E	MCM/ICM Summary Sheet	2320137

Turn Off the Light, Turn On the Night

Summary

Light pollution, caused by excessive or improper use of artificial light, brings adverse effects on both humans and the ecology. For community officials, it is significant to consider the balance between the light pollution and other factors such as public security when establishing intervention strategies. This report's target is building a suitable model to quantify the risk level of light pollution in different locations and giving governance measures accordingly. We are expected to consider representative metrics in the AHP model and screen out the most effective measures to reduce the damage of light pollution.

For problem 1, we divide the question into three phases: selecting metrics extensively and collecting related data, filtering key metrics, and calculating the quantization formula. Firstly, we identify numerous possible metrics based on existing research and our common sense. Then we establish an assessment model: **Light Pollution Risk Level Assessment Model**. Next, we pick 7 key metric through comparing the importance of these metric. Using the Analytic Hierarchy Process(**AHP**), we quantify the weight of 7 metrics. After the weights and values of these metrics are determined, our model can quantify the level of light pollution risk in an area and divide it into different levels.

For question 2, we randomly select 4 representative locations and apply our risk assessment model to four specific regions. After quantifying and grading the light pollution levels of these locations, we further interpret the each result according to the actual local conditions.

To solve the third problem, based on the established light pollution risk assessment model, we start with the most important metrics and creatively propose three targeted intervention measures. For each measure we explain in detail how specific actions will change the impact of light pollution.

In the case study, we compared the effects of different intervention strategies on reducing light pollution in two specific places. After that, we use the **Entropy Weight Method** to analyze the change of the weight of the AHP model to compare the effects of different strategies and obtain the optimal intervention strategy for the designated area and how it affects from both negative and positive perspective.

Finally, we perform an accuracy analysis of our model, analyze the strengths and the weaknesses of our model. Then we consider the possible further improvement of the model in the future. At the end of the article, a one-page flyer for city area is displayed to promote the most effective measures to reduce the negative impact of light pollution and call for everyone to participate.

Keywords: Light Pollution; Risk Level Assessment Model; AHP; Entropy Weight Method

Contents

1 Introduction

1.1 Problem Background

Light pollution, which refers to the problems caused by the excessive use of lighting systems by humans, is not uncommon. According to a recent study [1] published in *Science*, artificial light sources have illuminated the night sky more and more brightly in the past ten years, so that the number of stars visible to the naked eye has decreased significantly.

Currently, light pollution has many negative effects[2] whether in big cities or remote areas: disturbing people's sleep[3], affecting the growth of plants, changing the migration patterns of animals[4] and so on. However, for some dimly lit communities, light pollution can be reduced community crime rates and have a positive impact. As such, the impact of light pollution varies by region, and any interventions to light pollution should also vary by region.

In order to support the work of **ICM**, we will establish a model and use it to develop intervention strategies to address the negative impact of light pollution as possible. At the same time, we will verify our model in different locations and simulate the implementation of intervention strategies.

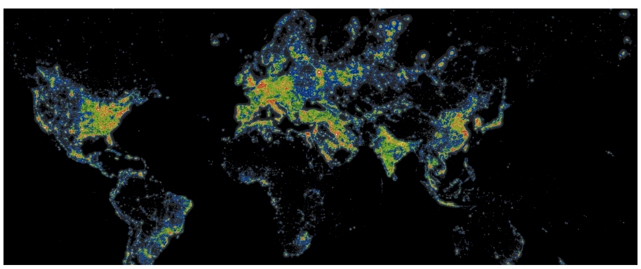

Figure 1: Light Pollution World Map

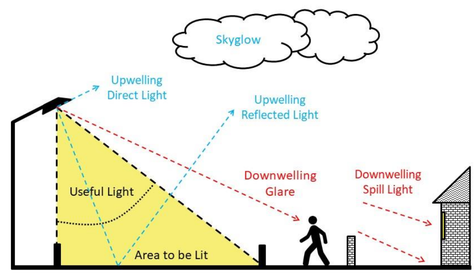

Figure 2: Components of Light Pollution

1.2 Restatement

Based on a full understanding of the problem, we're required to complete the following tasks:

- **Develop a widely applicable assessment model to determine the light pollution risk level of a location**, and classify the level according to the model.
- **Apply our assessment model on four different locations**, which are protected lands, rural communities, suburban communities, urban communities, and analyze the light pollution risk levels in each location.
- **Propose three different intervention strategies to minimize the level of light pollution risk**, and explain in detail how specific actions in the strategies affect light pollution.
- **Decide which intervention will be most effective at a particular location**, and discuss how this impacts the level of risk.
- **Make further exploration of the sensitivity of our models, and determine the strengths and weaknesses.**

1.3 Our Work

COMAP's lighting control mission requires us to measure the effects of light pollution in different locations and propose corresponding strategies to reduce the impact of light pollution on humans and non-humans. Through data collection combined with existing research, our work is as follows:

- To solve the first problem, we combined actual data and existing research, and finally selected 7 metrics that affect the risk level of light pollution. The metric data corresponding to light pollution in countries all over the world come from official websites of authoritative organizations. We preprocessed and studied the metric data, quantify the weight of each metric by using the Analytic Hierarchy Process (AHP), and established a wide range of light pollution risk level assessment models applicable to different locations.
- To solve the second problem, we randomly selected four representative locations, measured the light pollution risk metric of different locations according to the established assessment model, calculated the level of light pollution risk in each place, and analyzed the degree according to local conditions.
- To solve the third problems, based on the analysis of the existing light pollution risk level assessment model and four cases, we creatively proposed three targeted intervention measures to reduce the negative impact of light pollution as much as possible.
- Furthermore, we compared the effects of different intervention strategies on reducing light pollution in two specific places, and used the entropy weight method to analyze the metric weight of the AHP model, so as to obtain the optimal intervention strategy for the designated area as well as how it affects.
- Next, we analyze the accuracy of the model and its strengths and weaknesses. Finally, we made a one-page flyer to promote the most effective measures to reduce the impact of light pollution in the specified location and call for everyone to join the action.

Our work can be summarized by Figure 3.

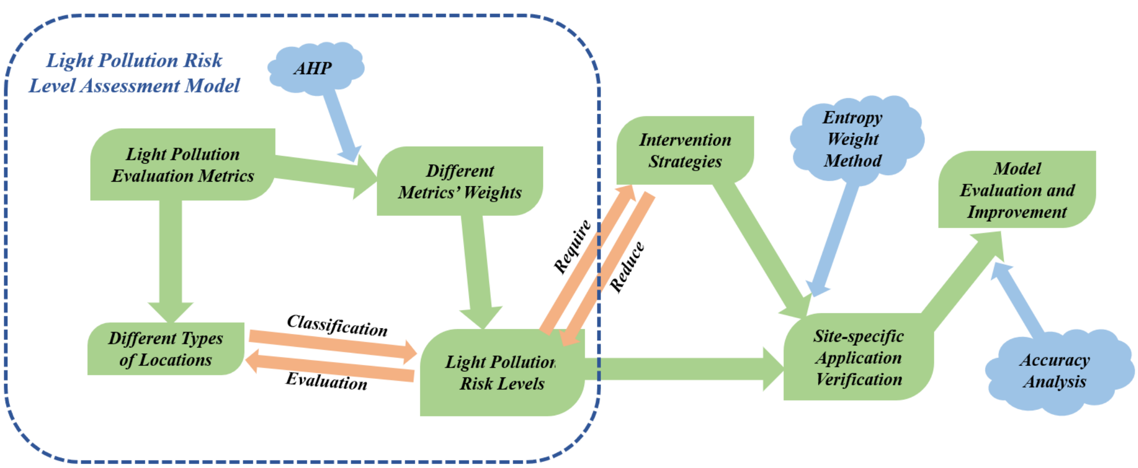

Figure 3: General Work Flow Chart

2 Assumptions and Notations

2.1 Assumptions

We make the following fundamental assumptions to simplify the problem, each of which is properly justified.

- **Assumption 1: Most of the effects of light pollution come from nighttime.**
  Justification: Because light pollution is prevalent at night, we consider to collect data at night to consider the effects of light pollution, which is realistic and reasonable.
- **Assumption 2: The level of light pollution will not change suddenly.**
  Justification: To make it is convenient for us to calculate the level instead of considering the time, we assume that the level of light pollution remains stable for a certain period of time.
- **Assumption 3: Light pollution is slightly affected by the ecological factors.**
  Justification: The adverse effects of light pollution on a certain place may vary in local ecological, economic and social factors, but our model selects representative places, and the differences in these factors can be approximately ignored.
- **Assumptions 4: The regions and cases we selected are fully representative.**
  Justification: Because we randomly selected four regions with different geographic locations and different geographical features.

2.2 Notations

We've included some notations below for your convenience, Other specific notations, if necessary, will be demonstrated and illustrated when we build models.

Table 1: Notations

Symbol	Description
a_{ij}	the relative importance of the metric i to metric j
λ_{max}	the largest characteristic root of the judgment matrix A
A	the judgment matrix
C.R.	consistency ratio
R.I.	consistency index
w_i	the weight of the metric i
$L.P.$	the light pollution risk level of a certain location
C_i	the level of the metric i
e_j	the entropy value of metric j
p_{ij}	the value of the elements in the probability matrix

3 Light Pollution Risk Level Assessment Model

3.1 Selection of Metrics

In order to establish the level of light pollution risk in an area as accurately and objectively as possible, we need to develop a metric model that can be widely adapted. After reading a lot of literature and collecting a lot of data[5], we selected the following seven main metrics to build our model: light intensity, light source type, light source density, lighting time, control measure, meteorological condition, coverage area. The following tree is the conceptual explanation of these seven metrics:

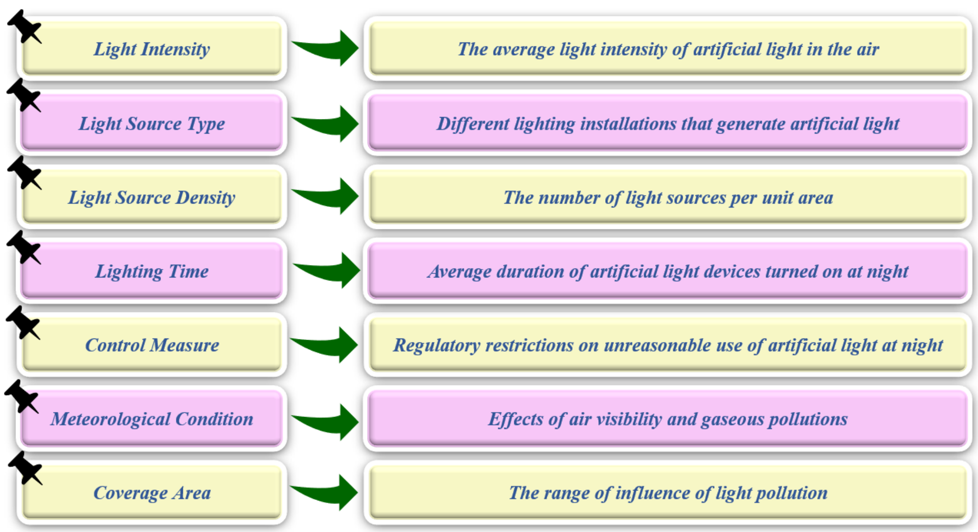

Figure 4: Seven Light Pollution Risk Metrics Concepts

We hope to quantify the risk level of light pollution as accurately as possible. To this end, we first classify the seven main evaluation metrics into five levels, and score them from 1 to 5 according to certain standards.The higher the index level, the greater its impact on the light pollution risk level. Below are some of the basis and value ranges by which we grade each metric:

Table 2: Five-level Classification Standard for Light Pollution Metrics

Metrics \ Levels	1	3	5
Light Intensity	<10lux	200lux∼500lux	>1000lux
Light Source Type	small lighting facilities	street and car lights	billboards, neon signs
Light Source Density	few light distribution	normal construction	bustling center
Lighting Time	<5h	7∼9h	>11h
Control Measure	strict management	moderate measures	few regulations
Meteorological Condition	excellent air quality	average air quality	poor air quality
Coverage Area	<1km	5∼20km	>45km

[1] 2 and 4 are not included in the table, indicating the median value of the above two adjacent cases.

3.2 Determine the Weight of the Metrics

After selecting the metrics of light pollution risk level, we need to determine the impact weight of these metrics to quantify the level of light pollution risk level of a location. Since the assessment of light pollution risk level is a decision-making problem of hierarchical cross-evaluation indicators, we decided to adopt the **Analytic Hierarchy Process (AHP)**[6], which is a multi-criteria decision-making method. The specific flow chart of the **AHP** is as follows.

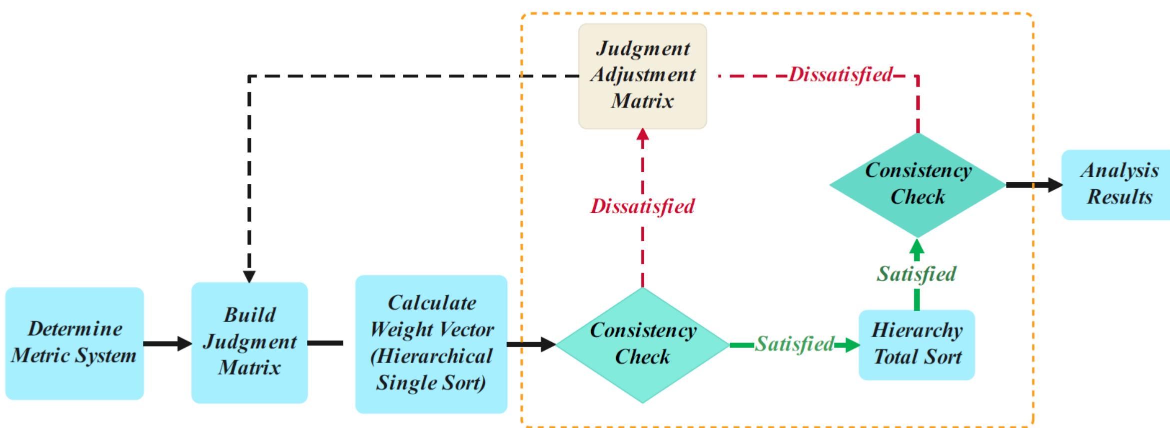

Figure 5: The Flow Chart of AHP

Firstly, we need to construct the judgment matrix of the above measurement metrics based on the evaluation scale standard of AHP. Each value in the matrix represents the contribution degree of one metric relative to another, which is divided into five levels, namely equal **Equal Strong, Weak Strong, Quite Strong, Very Strong, Absolution**. Give the measurement value of 1, 3, 5, 7, 9 to them, and set another four scales between the five basic scales. The meaning of each scale is shown in the table below

Table 3: AHP Assessment Scale Standard Chart

Assessment Scale	Assessment Scale	Illustration
1	Equal Strong	The degree of contribution is of equal importance
3	Weak Strong	Experience and judgment slightly favor
5	Strong	Experience and judgment strongly favor
7	Very Strong	Actually show a very strong preference
9	Absolution	Sufficient evidence to affirm an absolute preference

[1] 2, 4, 6, 8 are the intermediate values between two adjacent scales, between the two adjacent judgments. And if A is 3 compared to B, then B is 1/3 compared to A.

Based on the analysis of literature results and data verification [7], we made the judgment matrix of light pollution risk level metrics as follows. Assuming that the j element in the i row of the matrix is a_{ij}, the value of a_{ij} reflects the relative importance of the metric i to metric j, where i, j are the subscripts of the seven metrics listed in **Seven Metrics Tree 4**.

$$A = \begin{bmatrix} 1 & 2 & 4 & 3 & 5 & 7 & 8 \\ 0.5 & 1 & 2 & 2 & 4 & 5 & 6 \\ 0.25 & 0.5 & 1 & 1 & 2 & 3 & 3 \\ 0.333 & 0.5 & 1 & 1 & 2 & 2 & 3 \\ 0.2 & 0.25 & 0.5 & 0.5 & 1 & 2 & 1 \\ 0.142 & 0.2 & 0.333 & 0.5 & 0.5 & 1 & 1 \\ 0.125 & 0.167 & 0.333 & 0.333 & 1 & 1 & 1 \end{bmatrix} \tag{1}$$

Secondly, conduct a consistency test on the constructed judgment matrix. The first step is to calculate the **C.I.** according to the consistency index formula:

$$C.I. = \frac{\lambda_{\text{max}} - n}{n - 1} \tag{2}$$

where λ_{max} is the largest characteristic root of the judgment matrix A, and n is the order of A.

The second step is to obtain the value of the average random consistency inmricettextbfR.I. according to the average random consistency metric value table[7].

The third step is to calculate the consistency ratio **C.R.**:

$$C.R. = \frac{C.I.}{R.I.} \tag{3}$$

Substituting the matrix values into the calculation results in **C.I. = 0.0135**, **R.I. = 1.34 (n=7)**, the consistency calculation ratio **C.R. = 0.0102 < 0.1** is in the acceptance domain and the matrix can pass the consistency test.

Thirdly, according to the arithmetic mean method and the geometric mean method, the weight vectors are obtained respectively, and the average value of the two groups of weights is taken as the final influence weight of each index. The arithmetic mean method is calculated as follows:

$$\omega_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} (i = 1, 2, \cdots, n) \tag{4}$$

The geometric mean method is calculated as follows:

$$\omega_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{k=1}^{n} \left(\prod_{j=1}^{n} a_{kj}\right)^{\frac{1}{n}}} (i = 1, 2, \cdots, n) \tag{5}$$

Calculate the weight of each metric based on the data in the judgment matrix, and express them on the pie chart.

Table 4: Metrics' Weight Table

Metrics	Weight
Light Intensity	0.3755
Light Source Type	0.2331
Light Source Density	0.1197
Lighting Time	0.1178
Control Measure	0.0636
Meteorological Condition	0.0452
Coverage Area	0.0451

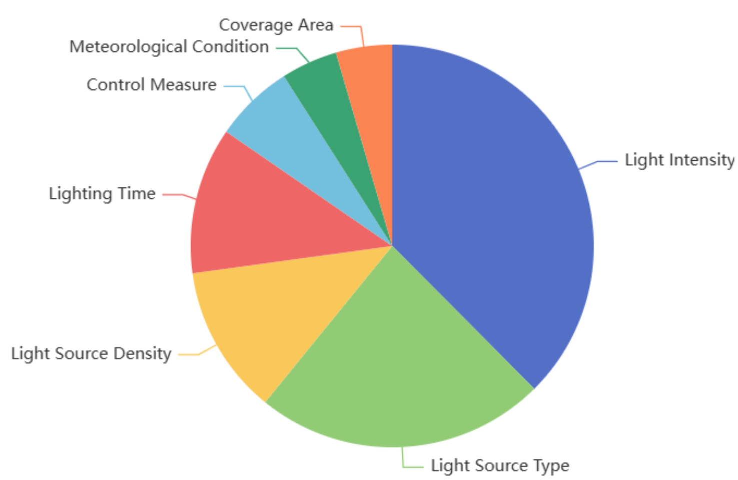

Figure 6: Metrics' Weight Pie Chart

Finally, through the above metrics and their weights, we can quantitatively calculate the light pollution risk level of a location.

$$L.P. = \sum_{i=1}^{n} C_i w_i \tag{6}$$

where

- $L.P.$ represents the light pollution risk level of a certain location.
- C_i represents the level of the metric i.
- w_i represents the weight of the metric i.

According to the calculated value, we divide the light pollution risk level of an area as follows:

Figure 7: Classification of Light Pollution Risk Levels Based on $L.P.$

3.3 Apply Metrics in Specific Places

After establishing a relatively completed assessment model of light pollution risk level, we will try to apply it to specific practice. In order to verify the rationality and comprehensiveness of the model, we will select four different locations for analysis and evaluation:a protected land location, a rural community, a suburban community and an urban community.

3.3.1 A Protected Land Location

Among protected land locations, we selected Yellowstone National Park as a representative example. Yellowstone National Park is a world-renowned national park, which is full of strange addresses and a wide variety of flora and fauna, and most of the areas are prohibited from human beings.

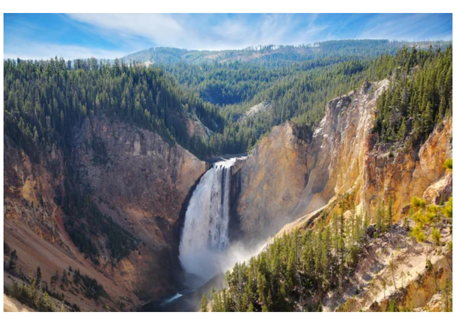

Figure 8: Yellowstone National Park

Figure 9: Matamata Town

3.3.2 A Rural Community

In the area of rural communities, we selected the small town of Matamata in New Zealand as a representative example. The town of Matamata preserves the natural landscape to the greatest extent, and small and medium-sized villages are scattered among them.

3.3.3 A Suburban Community

Among the areas of suburban communities, we have chosen Patras, Greece as a representative example. Patras, a beautiful mid-sized town, is located on the Mediterranean coast, which has a long history, low population and building density.

Figure 10: Patras

Figure 11: Hong Kong

3.3.4 An Urban Community

Among urban areas, we selected Hong Kong, the world's three major financial centers, as a representative. Hong Kong's equally long history has brought extreme prosperity, and the small land is crowded with humans and high-rise buildings.

3.3.5 Model Application and Result Analysis

We evaluated the seven metrics in the above four regions respectively, and calculated according to Formula 6 to obtain a quantitative assessment of the regional light pollution risk level. The summarized and processed data table is as follows:

Table 5: Grade Evaluation of Light Pollution Risk Metrics in Four locations

Levels \ Areas / Metrics	Yellowstone National Park	Matamata	Patras	Hong Kong
Light Intensity	1	2	4	5
Light Source Type	1	2	3	5
Light Source Density	1	2	3	5
Lighting Time	2	4	3	4
Control Measure	1	2	2	3
Meteorological Condition	1	1	2	4
Coverage Area	1	2	3	5
$L.P.$	1.1178	2.1904	3.2667	4.7098

Combining the above calculation results with tab 5grade of four locations, we can draw the following conclusions, and after each conclusion we will give a reasonable explanation:

1 **Light pollution risk level for Yellowstone National Park is: low.**

In Yellowstone National Park, due to strict government management measures, there is almost no human activity in the entire area, and the air quality in the natural environment is excellent. Artificial light can hardly affect anything in the park, so the low level of light pollution risk is justifiable.

2 **Light pollution risk level for Matamata Town is: medium.**

In the small town of Matamata, the natural landscape has been well preserved, and humans have only carried out a small amount of activities to build facilities, so there are no strong light source facilities and high light source density. The small area covered by the light source, combined with good air quality, makes the area a moderate risk of light pollution.

3 **Light pollution risk level for Patras is: high.**

In the town of Patras, there are well control measures and air quality. But people began to live together in a large number, and the buildings and roads everywhere made it inevitable to use a large number of different lighting facilities, and the density and intensity of light sources also increased, which had a great impact on light pollution. Therefore, the risk level of light pollution in the region is high.

4 **Light pollution risk level for Hong Kong is: very high.**

Hong Kong,one of the three world financial centers, the highest level of human development is reflected here. The row upon row of tall buildings, the constant flow of vehicles, all kinds of neon lights, and the lights that are lit all night are enough to affect the artificial light within a radius of tens of kilometers, and the control measures here are very weak. Undoubtedly it has a very high level of light pollution risk.

4 Intervention Strategies to Reduce Light Pollution

From Figure 1 at the beginning of this report, we can see that there are hardly many areas on the earth today that are not affected by light pollution, and where there are human traces, the light pollution caused by human activities is more significant. In order to reduce the risk level of light pollution in an area as much as possible, we need to formulate a series of reasonable intervention strategies. Here we propose three effective strategies, analyze and discuss the specific implementation of each strategy and the potential impact on the impact of light pollution:

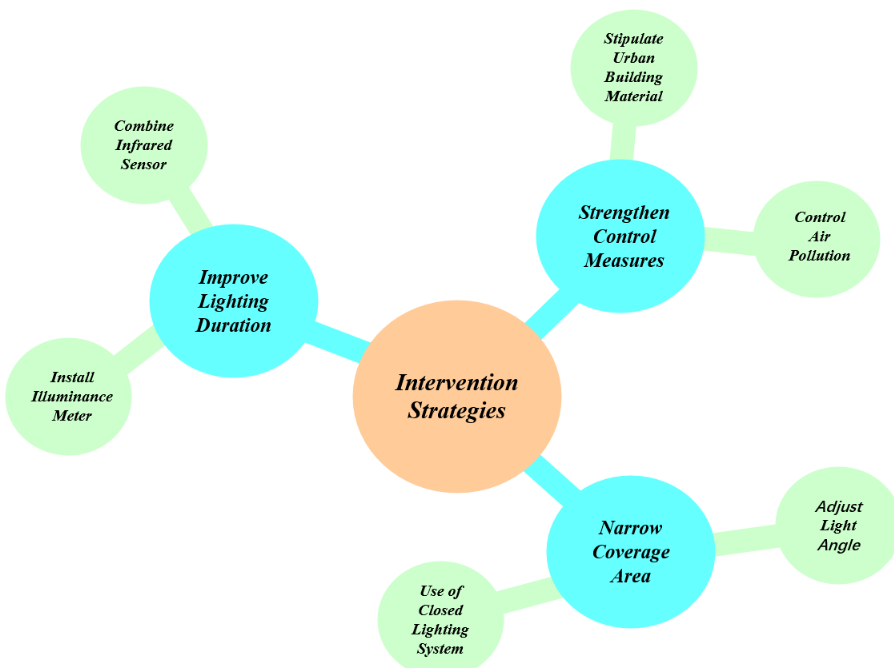

Figure 12: Light Pollution Intervention Strategies

4.1 Strengthen Control Measures

4.1.1 Specific Actions to Strengthen Control Measures

- **Stipulate urban building materials and promote materials that indicate rougher buildings**

  Enacting laws which will explict the material of building, prohibits the use of excessive glass curtain walls, mostly used in high-rise buildings in cities, which will produce a lot of reflective glare. Supervise the construction of urban buildings through city regulations to ensure the harmony of light in the city.

- **Control Air Pollution**

  Emission-emitting industries such as factories should be given strict emission limits, because the light will experience a lot of scattering in the air full of dust and smoke, making the possibility of sky glow greatly increase. Well-controlled air quality can make the Milky Way shine brighter in our skies.

4.1.2 The Impacts of Enhanced Control Measures

- **Controlling the glass curtain wall** will directly reduce the proportion of reflected glare, while the rough building surface will absorb a certain amount of lighting light, reduce light scattering into the atmosphere, and form light pollution. However, glass curtain wall is usually a symbol of the developed cities. It is also an important way for architects to express their artistry so the buildings in the city are likely to be boring without the glass curtain wall. Therefore, the control of glass curtain wall may cause changes in the city's image and reduce the city's tourism income.

- **Controlling air quality** can be said to be beneficial without any harm. It can not only effectively curb the spread of light pollution, but also give us and nature a healthy living environment.

Figure 13: Urban Glass Curtain Wall

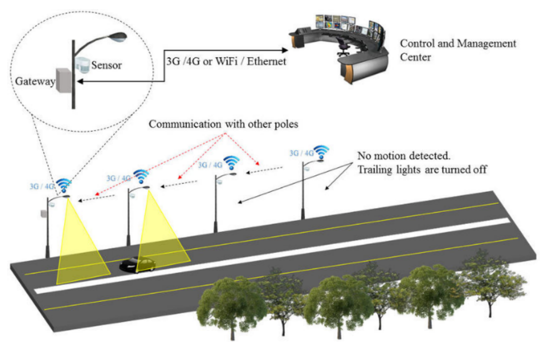

Figure 14: Lighting System with Infrared Senor

4.2 Improve Lighting Duration

4.2.1 Specific Actions to Improve Lighting Duration

- **Combine the infrared sensor with street light**

  The lights of this road are bright only when vehicles are detected by the infrared sensor. This method has great significance for rural areas, where population density is lower than urban areas, traffic flow is low, and even vehicles do not pass the road all night.

- **Install illuminance meters**

  The illuminance meter can be measured according to the light intensity in the environment, and the system with the illumiance meter is able to automatically turn on the city night lights when it is lower than a certain threshold-after all, avoiding unnecessary waste.

4.2.2 The Impacts of Improving Lighting Duration

These actions can reduce the working time of the lighting and save the energy. However, the use of infrared senor and the illuminance meter requires high technical level, consuming numerous labor and material resources in the beginning.

4.3 Narrow Coverage Area

4.3.1 Specific Actions to Narrow Coverage Area

- **Use of closed lighting system**

  The airtight lighting system can effectively prevent the leakage of indoor light. It is beneficial to maintain a bright environment with low-intensity light, which greatly saves power consumption, and can also effectively suppress the incidence of external light.

- **Adjust the light angle**

  For street lamps on the street, the lampshade can be set more round so that the light has a small divergence angle. For large-scale light-emitting devices such as neon lights, the light-emitting direction should be directed toward the ground as much as possible, instead of shooting into the sky, which will cause great energy loss.

Figure 15: Light Range and Star Brightness

4.3.2 The Impacts of Narrowing Coverage Area

After using the closed lighting system, the divergence of light is greatly reduced, which will have a great positive impact on the natural landscape inside or around the city. Human beings, animals and plants will have a normal circadian rhythm. Meanwhile, suppressing the emission of artificial light requires professional design drills and a large number of simulations, and greater light source density needs to be used to ensure the intensity of light.

5 Case Study: Applying Our Strategies

In order to apply our measurement standard model and intervention strategies, the following will select the optimal light pollution intervention strategy for rural community and urban community, and use the entropy weight method to analyze how it affects the risk level.

5.1 Optimal Intervention Strategies

According to the content of the three intervention strategies we described before, after applying them to specific locations, the local light pollution risk metrics will also change. Firstly, we will quantify the light pollution risk level of a certain place under different strategies according to the metric weight coefficient obtained by the **AHP** method(see table 4), and compare the change degree of light pollution risk level of a certain place under different strategies.

In order to simplify the expression, we refer to the original metric value of Matamata Town as **MT** for short, and the metric values of Matamata Town after implementing different intervention strategies is abbreviated as $\boldsymbol{MT_1, MT_2, MT_3}$ respectively. Similar to Matamata Town, we abbreviate the original metric values of Hong Kong as **HK**, and the Hong Kong metric values under different strategies is abbreviated as $\boldsymbol{HK_1, HK_2, HK_3}$. The standard evaluation model is used to weight the index values to obtain the respective light pollution risk levels. The results are shown in the table below:

Table 6: Table of Light Pollution Metrics in Matamata and Hong Kong

Metrics \ Strategies	MT	MT_1	MT_2	MT_3	HK	HK_1	HK_2	HK_3
Light Intensity	2	2	2	1	5	3	5	4
Light Source Type	2	2	2	1	5	5	5	5
Light Source Density	2	2	2	2	5	5	5	5
Lighting Time	4	4	3	4	4	4	3	4
Control Measure	2	1	2	2	3	1	3	3
Meteorological Condition	1	1	1	1	4	2	4	4
Coverage Area	2	1	1	1	5	4	4	3
$L.P.$	2.1904	2.0817	2.0275	1.5367	4.7098	3.6961	4.5469	4.2441

By comparison, we find that $\boldsymbol{MT > MT_1 > MT_2 > MT_3}$, where $\boldsymbol{MT_3}$ is the only case where the light pollution risk level is low, while the remaining three are medium risk levels. Therefore, **Narrow Coverage Area strategy** is most effective for rural communities.

Similarly, we found that $\boldsymbol{HK > HK_2 > MT_3 > MT_1}$, of which $\boldsymbol{HK_1}$ is the only case with a high light pollution risk level, and the rest are all extremely high risk levels. As a result, **Strengthen Control Measures strategy**is most effective for urban communities.

5.2 Analyze the Impact of Different Strategies

Next, we perform an entropy weight analysis on the data using the entropy weight method and try to explain how the specific strategies selected above affect the light pollution risk level in Matamata town and Hong Kong.

Entropy is a concept in information theory and a measure of uncertainty [8]. According to the definition of information entropy, the degree of dispersion of metric can be judged according to the available entropy value of the metric. The smaller the entropy value, the greater the degree of dispersion of the metric, and the greater the impact weight of the metric on the comprehensive evaluation.

In our model, the entropy value of the metric can be calculated according to the value of the light pollution risk metrics in a certain location under different strategies. The entropy value calculation formula of the metric j is as follows:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln\left(p_{ij}\right)(j = 1, 2, \cdots, m) \tag{7}$$

where e_j is the entropy value of metric j, p_{ij} is the value of the elements in the probability matrix based on the values of Light Pollution Metrics table 6.

Then we can calculate the weight of the metric based on the metric entropy value

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m}(1 - e_j)}(j = 1, \ldots, m) \tag{8}$$

where w_j is the entropy weight of each metric.

Calculate the entropy weight of the light pollution metric in two locations separately, and draw the weight histogram as follows:

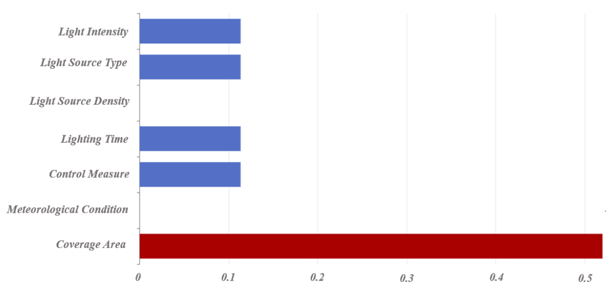

Figure 16: Matamata Entropy Weight Histogram

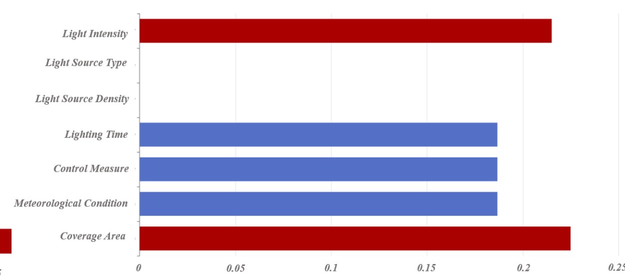

Figure 17: Hong Kong Entropy Weight Histogram

Analyzing the weights of each indicator in Matamata town, we find that among the three different strategies, the coverage metrics dominates (which has the largest weight). That means, changes of coverage are most likely to reduce the overall light pollution risk level, which is consistent with the results calculated by our assessment model. In the third strategy, the closed lighting system we advocate and the adjustment of light angle can suppress the divergence of light to a large extent.

Similarly, analyzing the entropy weights of various indicators in Hong Kong, we find that the entropy weights of light intensity and coverage are the largest and almost equal. It shows that these two metrics play a leading role in the process of implementing measures to suppress the impact of light pollution in this area. In strategy one, we propose two control measures, regulating building materials and controlling air pollution. Strong government regulations can well suppress the scattering of light and avoid glare and other situations that endanger people's health. In addition, the weight of meteorological conditions and control measures should not be underestimated.

6 Model Evaluation

6.1 Model Accuracy Analysis

We will use a linear multiple regression method to calculate the corresponding index coefficient and compare the return coefficient results with the coefficient of the AHP model to study whether the AHP model is accurate. We divide the data in the first section into 4 parts and use the four datasets to do a multiple linear regression. We compare the four sets of coefficients from the AHP model to get the line chart below:

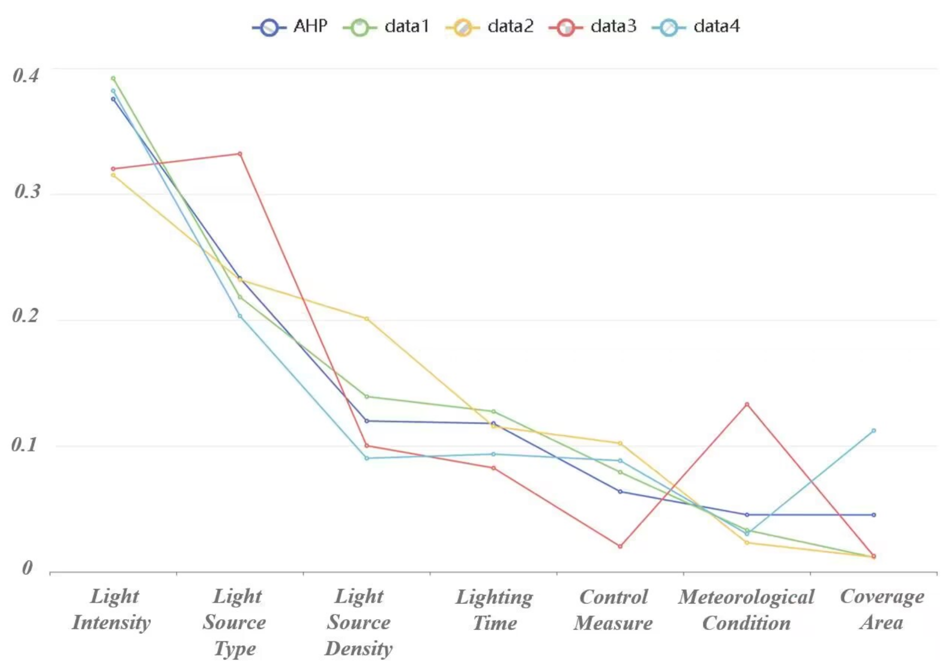

Figure 18: AHP model and linear regression coefficient folding diagram

The average gap between the parameters of the multi -linear regression and the AHP model is 12.41%. Since our data is a discrete data, the impact of about 10% of the parameter error on the final risk rating does not exceed 10% of the highest level of risk level. 0.5 less than 1 so it will not change the risk level more than one level. Therefore, in the actual application of the AHP model, although there is a slight error compared to the multi -linear regression, the error will not affect the ultimate level of risk. At the same time, AHP has good applicability and the return of multiple sets of data is more consistent.

6.2 Strengths

- **Strong applicability of the model**
  In the accuracy analysis of the AHP model, although the AHP model has an error with the specific weight coefficient in each region, the error has little effect on the risk level level. Therefore, the AHP model is suitable for quantifying the level of risk around the world.

- **Extensive evaluation metric system**
  Evaluating the risk level of light pollution with a rich and comprehensive metric system provides a strong theoretical basis for intervention strategies.

- **Proper integration with local realities**
  When discussing the most optimal intervention strategy of a certain location, fully consider the characteristics of local light pollution metrics to minimize the negative impact of light pollution.

6.3 Weaknesses

- **Slow response to changes in risk levels**
  Because we level the data, the resulting risk level of light pollution is also discrete. So when the light pollution level of a city changes, our model cannot respond to this change in time until the city's light pollution risk level crosses a level. This is likely to lead to cities not being able to make remedial measures in time, causing greater light pollution damage.

- **Randomness representing regions**
  Although we try our best to select representative and well-known areas as the actual application locations of the model, due to the differences between regions around the world, we cannot guarantee that there may be a small number of areas where the light pollution risk level is not suitable for our model.

- **No consideration of more possible influencing metrics**
  Limited by the number of metrics in the AHP model, we did not include some factors that may also affect the risk level of light pollution, such as geographical location, population density, degree of development, etc.

6.4 Possible Improvements

When considering the risk level of light pollution in a certain place, our model metrics focus on the factors that cause the light pollution, without taking into account the differences in biological and non-biological factors in the location itself. Therefore, on the basis of our existing model, we can further quantify and analyze the differences in the impact of the same light pollution level on different locations.

In addition, when using AHP to analyze the risk level of light pollution, there are some subjective factors. In the subsequent model, the metrics can be further optimized in combination with methods such as Topsis[9], taking into account more real-world situations.

ICM/MCM

TURN OFF THE LIGHT TURN ON THE NIGHT

BY AN ICM SQUAD

INTRODUCTION

Light pollution in cities is becoming more and more serious, and it can have a major impact on our health, safety and environment. Responding to the call of the ICM, our team is dedicated to finding practical and effective ways to reduce light pollution while keeping our cities safe and vibrant. Here are some ways we take action:

ACTION A

Stipulate urban building materials and promote materials that indicate rougher buildings. Enacting laws which will explict the material of building, prohibits the use of excessive glass curtain walls, mostly used in high-rise buildings in cities, which will produce a lot of reflective glare.

ACTION B

Emission-emitting industries such as factories should be given strict emission limits, because the light will experience a lot of scattering in the air full of dust and smoke, making the possibility of sky glow greatly increase. Well-controlled air quality can make the Milky Way shine brighter in our skies.

NOW JOIN US

We believe that educating communities about the importance of responsible lighting practices is key to promoting healthier, more sustainable urban environments. We encourage everyone to join us as we begin by turning off the first lights of the day.

Lighting Up Smart for a Brighter Urban Future!

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Appendices

```
import numpy as np
from functools import reduce

'''1.Input data'''
print("Please enter the judgment matrix dimension:")
n = eval(input())
print("Please enter the judgment matrix:")
A = np.ones((n, n))
for i in range(n):
    A[i] = input().split(" ")
    A[i] = list(map(float, A[i]))
print("The judgment matrix is:\n{}".format(A))

'''2.Consistency Check'''
w, v = np.linalg.eig(A)
wIndex = np.argmax(w)
wMax = np.real(w[wIndex])
print("Maximum eigenvalue value:{}".format(wMax))

CI = (wMax - n) / (n - 1)
print("CI = {}".format(CI))
# RI is from "Judgment scales and consistency measure in AHP".
# Procedia Economics and Finance, 12(2014).
RI = [0, 0, 0.0001, 0.52, 0.89, 1.12, 1.26, 1.36,
      1.41, 1.46, 1.49, 1.52, 1.54, 1.56, 1.58, 1.59,
      1.5943, 1.6064, 1.6133, 1.6207, 1.6292]
print("RI = {}".format(RI[n]))
CR = CI / RI[n]
print("CR = {}".format(CR))

# make consistency check
if CR > 0.1:
    print("The consistency of the judgment matrix A is not acceptable.")
else:
    print("The consistency of the judgment matrix A is acceptable.")

'''3.Normalization'''
lineSum = [sum(m) for m in zip(*A)]
D = np.zeros((n, n))
for i in range(n):
    for j in range(n):
```

```
        D[i][j] = A[i][j] / lineSum[j]
print("The normalized judgment matrix is:\n{}".format(D))

'''4.Calculate weight'''
# Arithmetic mean method to calculate the weight
ans = np.zeros(n)
for i in range(n):
    ans[i] = np.average(D[i])
print("The result of Arithmetic mean method is:\n{}".format(ans))
# Geometric mean method to calculate the weight
ans = np.zeros(n)
for i in range(n):
    ans[i] = reduce(lambda x, y: x * y, A[i])
    ans[i] = pow(ans[i], 1 / n)
ans = [e / np.sum(ans) for e in ans]
print("The result of Geometric mean method is:\n{}".format(ans))
# Eigenvalue method to calculate weight
ans = np.zeros(n)
vIndex = np.argmax(v)  # Eigenvector index corresponding to largest eigenvalue
vMax = np.real(v[:, vIndex])
ans = [e / np.sum(vMax) for e in vMax]
print("The weight calculation result of the eigenvalue method is:\n{}".format(ans))
```