Optimizing public street lighting and redesign of public road lighting based on DIALux and fuzzy logic

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Abstract. Road lighting is one of the most important infrastructures in an urban area, one of its main functions is to provide comfort for road users as well as crime prevention at night. But besides having various functions, public street lighting systems must comply with standards and also pay attention to aspects of energy efficiency. This study discusses the optimization of using artificial intelligence with civil fuzzy logic methods to obtain a level of evenness that is in accordance with the standard, with input variables such as road width, pole height, lamp power and mounting distance between poles. Then the results of the Mamdani fuzzy logic are used as the basis for re-design input using DIALux and some additional input according to the standard criteria contained in the DIALux software. The results of this study indicate that both the level of evenness and other aspects have met the standards and also have energy savings of up to 58.6% of the existing conditions, this research is expected to be a recommendation in the design of street lighting.

1. Introduction

Public street lighting is one of the important facilities that must be present in a road system, whether in a busy or not crowded neighbourhood [1,2]. Public street lighting has many functions that can facilitate activities in low light such as environmental safety or prevent crime and to provide comfort and beauty of the road environment [3–6]. But besides having many benefits, PJU is also one of the biggest contributors to electricity waste in the night [7]. Therefore, a more optimal PJU system is needed both in terms of energy efficiency and comfort provided from the lighting [8]. The types of conventional lamps that are still widely used in PJUs are classified as wasteful and the lamps used have a short life span, seeing from the existing system the use of this type of lamp is the most influential on the energy consumption produced [9].

Energy efficiency is defined as methods, techniques and principles that make it possible to produce the same output with less energy use or get a larger output with the same amount of energy [10,11]. Energy efficiency is now a very popular topic because the world's need for energy continues to grow every year [12]. In terms of regulations, there are many regulations that emphasize energy efficiency. As stated in Law No. 30/2007 and Government Regulation No. 70/2009 concerning energy conservation, energy efficiency is the responsibility of all parties, both the government (central and regional), the private sector, and the community.
The aim of the research is to find the best method that can reduce waste both in terms of energy and financial costs incurred for operational costs [13]. In this case, the research is intended to present an energy-efficient smart street lighting system based on fuzzy logic.

2. Research methods
This research was conducted using secondary data obtained from the PJU evaluation project of the city of Bandung by the Department of Electrical Engineering Education and the Department of Highways in Bandung in 2019, the object of research is on one of the quite busy streets in the city of Bandung, West Java, Indonesia. As can be seen in Figure 1, Roads in this study in accordance with SNI 7391: 2008 belong to the type of primary collector road, located at coordinates 6° 54'26.1" S 107° 36'15.9" E (from the north) and 6° 54'45.2" S 107° 36'14.3" E (from the south) has a length of 598 m, width 15 m, and a total of 13 PJU poles are installed. Illumination measurements are carried out using the point by point method, which measures the illumination value at nine points of light namely: three points under the lamp, three points in the middle of the road, and three points across the road. The type of PJU used is single row (one side) with an average height of 8.84 m. The lamps used are High Pressure Sodium (HPS) with Philips SON 250W E E40 CO 1SL / 12 type and Philips SRP 822 as the housing. The procedure of this research is shown in Figure 2.

![Figure 1. Location of research object.](image-url)
2.1. Data processing method
In this study, the instrument used was MATLAB software used as data processing and PJU design using mamdani fuzzy logic with the aim of obtaining an average illumination value in accordance with SNI, then the PJU design was implemented using DIALux software with simulated input which is the result of the output Mamdani fuzzy logic. After the data has been collected, this research design is planned to go through several stages as follows:

- Looking for PJU data to be used as input material from Mamdani fuzzy logic.
- Conduct data collection of road characteristics in the study area such as: road width, pole height, lamp power used, distance between poles and so on.
- Processing data for mamdani fuzzy logic input which will be used as a design to get standard illumination values using MATLAB.
- Implement design and optimization using the DIALux evo application with the input used is the result of Mamdani fuzzy logic.
- Processing design data to find out the use of electrical energy.

2.2. Simulation using Mamdani fuzzy logic
The first step in designing using the Mamdani fuzzy logic is the formation of a fuzzy set. In finding illumination values that are in accordance with the standards, the data or variables used include road width, pole height, lamp power used and also the installation distance between the poles.

After determining the variables, then each variable must make a grouping of membership functions for each variable. This is done to get maximum results in finding the illuminance value. With the interrelated variables and each variable has its own membership function, the fuzzy mamdani logic will determine the output value in accordance with the interrelation of each variable.

3. Results and discussion
This study uses a fuzzy inference system that is a rule system based on fuzzy logic which is used as a tool to represent different knowledge about a problem, as well as to model the interactions and relationships that exist between these variables. Some of the inputs used to get the appropriate illuminations include the width of the road, the power of the lamp used, the height of the pole to be used and the distance between the poles. After getting the results from fuzzy logic, the DIALux application in this study is used as a design implementation and optimization.

3.1. Existing condition
The type of public road lighting used in the study area is a single row installed on the left side of the road with a height of poles differing from one pole to another with an average height of 8.84 meters, for the distance between the poles is not uniform with the average 46 m has the closest distance of 39.47 m and the farthest distance of 63.113 m as can be seen in table 1. The lamp used is the Philips SON 250W E E40 CO 1SL / 12 which is a type of high pressure gas lamp (high intensity discharge) or commonly called SON has 250W of power, and Philips SRP 822 as a housing.
Table 1. Study area pole specifications.

| Pole | Distance to next pole | Pole angle | Pole height | Pole arm length | Slope   |
|------|-----------------------|------------|-------------|-----------------|---------|
| 1    | 43,497                | 78,6       | 8,952       | 1,805           | 9,133   |
| 2    | 43,558                | 78,3       | 9           | 1,863           | 9,191   |
| 3    | 44,522                | 77,3       | 8,767       | 1,975           | 8,987   |
| 4    | 44,795                | 75,8       | 8,895       | 2,25            | 9,176   |
| 5    | 48,044                | -          | -           | -               | -       |
| 6    | 40,329                | 76,6       | 8,798       | 2,096           | 9,045   |
| 7    | 42,571                | 79,6       | 8,804       | 1,615           | 8,951   |
| 8    | 43,516                | 78,9       | 8,863       | 1,738           | 9,032   |
| 9    | 45,134                | -          | -           | -               | -       |
| 10   | 39,47                 | 76,6       | 8,794       | 2,095           | 9,041   |
| 11   | 50,371                | 78,8       | 8,862       | 1,754           | 9,033   |
| 12   | 63,113                | 77,6       | 8,81        | 1,937           | 9,021   |
| 13   | 49,08                 | 77         | 8,785       | 2,028           | 9,017   |
| Average | 46                     | 77,736364 | 8,8481818 | 1,9232727      | 9,057   |

In accordance with SNI 7391: 2008, the level of evenness of light on primary collector road types is 3-7 lux. For data on the average illumination value of PJU the study area has fulfilled SNI which is 4.57 lux, but in reality the value of evenness of light in the study area is not evenly distributed which causes some points to look bright and some are dim. That happens because there are several PJUs that are blocked by external factors such as trees, so the illumination value is very small. Besides that, internal factors also influence different illuminations such as lamp life and other external factors such as external light can influence the average illuminance in the study area PJU. This will affect road users and can disrupt the concentration of drivers at night and can also increase the likelihood of crime due to road conditions that are too dark.

3.2. Optimization using the Mamdani fuzzy inference system

In designing and optimizing using fuzzy inference systems, the MATLAB software is used as a tool to get maximum results. Fuzzy inference system is a rule system based on fuzzy logic which is used as a tool to represent different knowledge about a problem, as well as to model the interactions and relationships that exist between these variables. The fuzzy inference mamdani system is proposed to get an even illumination result in accordance with SNI. Some of the inputs used to get the appropriate illuminations include the width of the road, the power of the lamp used, the height of the pole to be used and the distance between the poles.

3.2.1. System modelling framework. The formation of fuzzy set is the first step taken when using the mamdani method as can be seen in Figure 3. In this study there are five fuzzy variables which are divided into four input variables and one output variable, then will be modelled such as road width, pole height, lamp power, the distance between the poles and the average illuminance as an output variable.
Figure 3. Fuzzy set formation.

3.2.2. **Input.** In the fuzzy inference system in this study using 4 input variables that are used as input data in finding illumination values to fit the SNI. These variables such as the width of the road, the height of the pile installation plan, the amount of light power to be installed and the distance between one pole with another pole.

- **The width of the road**
  It is a plan or condition of the existing width of the road in meters that will be used as the basis for modelling. In this study the determination of the width of the road refers to SNI 7391: 2008 and PP No 34 of 2006, which in one of its contents gives the standard width of the existing road in Indonesia. The domain value of the width of the road used is as follows:
  1) Narrow : (3-7) meter
  2) Medium : (6-10) meter
  3) Wide : (9-13) meter
  4) Very wide : (12-16) meter

- **Pole height**
  It is a plan or condition of the existing height of the mast in meters that will be used as a basis for modelling. In this study the determination of pole height refers to SNI 7391: 2008, which in one of its contents gives the standard PJU pole height in Indonesia. Domain values of pole height are as follows:
  1) Pole Height 1 : (5-9) meter
  2) Pole Height 2 : (8-12) meter
  3) Pole Height 3 : (11-15) meter

- **Lamp power**
  Is the magnitude of the lamp power in watts that will be used in the simulation, the lamp power taken in this study uses existing types of LED lamps and has been widely on the Indonesian market and also refers to SNI 7391-2008. The domain values of the lamp power used in this study are as follows:
  1) Lamp Power 1 : (20-60) watt
  2) Lamp Power 2 : (50-90) watt
  3) Lamp Power 3 : (80-120) watt
  4) Lamp Power 4 : (110-150) watt

- **Distance between poles**
  Distance between poles is the distance of the installation point between one pole and another pole measured in meters. In determining the distance between the poles must adjust to the condition of the existing road width, height of the installation pole and also the power of the lamp to be used but still must refer to SNI in this case SNI 7391-2008. The domain values of the distance between the poles used in this study are as follows:
3.2.3. **Rule base.** In making this rule-based system has a set of facts that represent working memory. This rule covers every action that must be taken in the process and resolution of the scope of the problem needed. In this study as shown in Figure 4 there are rules that have been set to adjust the width of the road and select the lamp power selection, the height of the pile and the distance between the piles to get an average illumination in accordance with SNI. In this system a total of 144 rules have been established.

3.2.4. **Output.** Output is the result of the process of input and rule base that produces a statement to get the average illumination value in accordance with SNI, obtained in lux units. In this study, the average illumination was taken according to the SNI regulations here. The following domain values of the distance between the poles used in this study are as follows:

1) Local road illuminations : (2-5) lux  
2) Collector road illumination : (3-7) lux  
3) Arterial road illumination : (11-20) lux

3.2.5. **Rule viewer.** Rule viewer is useful to see the flow of fuzzy reasoning in the system, including mapping all inputs given to each variable as can be seen in Figure 5. To get the desired illumination average value and in accordance with SNI, the initial step is to determine the width of the road as a basis for can determine and adjust other variables such as the height of the pole that must be used, the appropriate lamp power to meet the standards and also the distance between the poles in order to achieve the desired average illumination value.
With the width of the existing study area road being 15 m and it is a secondary collector type road, after SNI the road must have an illumination value of 3-7 lux. Based on the results of the design, the values obtained for achieving the average road illumination in the study area are:

1) Pole Height : (9-12) meter
2) Lamp Power : (40-110) watt
3) Pole Distance : (35-49) meter

3.3. Redesign of PJU design using DIALux

In accordance with the results of fuzzy logic, the lamp power to meet the requirements of the average illumination value of the study area is in the range of 40-110 watts. So in this study using the type of Philips BGS213 T25 1 XLED75-4S / 830 DM10 lamp with the specifications as in Table 2 and Fig 6 as the physical form and the following light distribution:

| Manufacture | Philips |
|-------------|---------|
| Lamp Type   | LED     |
| Type        | BGS213 T25 1 XLED75-4S/830 DM10 |
| Nominal Voltage | 220-240 V AC, 50/60 Hz |
| Electrical power | 56 Watt |
| Lumination  | 6500 lm |
| Luminous Efficacy | 120 lm/W |
After determining the type of light source, the next step is to enter the road profile data in the study area. Data needed include: parameters of road conditions, road width, sidewalk width, sidewalk height, and lamp type. After entering the road parameter data then next is to enter the value of the plan variable to be simulated in DIALux. These variable data include the results obtained from optimization using fuzzy logic and also some additional variables that already exist in DIALux. These variables include the height of the pole and the distance between the piles obtained from the optimization of fuzzy logic, then light overhangs, pole distance from the roadway, boom angle, as shown in Figure 7.

When all of these variables have been fulfilled, the simulation process on DIALux can be run. After that DIALux brings out the best results from the simulation run, the results can be seen in Figure 8 for the colour index of the illumination distribution and after knowing the colour index of the illumination distribution, we can find out the illumination value from various points along the way. In total there are 153 light points that can be seen as in Table 3, from 153 light points obtained an average illumination value of 5.42 lux, with the largest illumination value of 7.25 lux and the smallest 3.68.
3.4. Use of electric energy

In calculating the use of electricity, this study is based on the regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 28 Year 2016 regarding electricity tariffs wherein it is stated that the electricity tariff group for the purposes of PJU at low voltage is of type P-3

### Table 3. Illumination values from the simulation results of the highway.

| Horizontal illuminance [lx] | Em [lx] | Emin | Emax [lx] | g1 | g2 |
|-----------------------------|--------|------|-----------|----|----|
| 15.117                      | 4.97   | 4.64 | 4.20      | 3.88| 3.70|
| 13.450                      | 5.83   | 5.48 | 4.95      | 4.58| 4.47|
| 11.783                      | 6.60   | 6.10 | 5.48      | 5.02| 4.91|
| 10.117                      | 7.01   | 6.46 | 5.78      | 5.28| 5.16|
| 8.450                       | 7.13   | 6.57 | 5.89      | 5.34| 5.22|
| 6.783                       | 7.04   | 6.45 | 5.76      | 5.24| 5.16|
| 5.117                       | 6.86   | 6.20 | 5.48      | 5.03| 4.90|
| 3.450                       | 6.26   | 5.57 | 4.92      | 4.53| 4.47|
| 1.783                       | 4.68   | 4.15 | 3.80      | 3.68| 3.76|
| Em [lx]                     | 4.342  | 7.286| 10.058    | 12.971| 15.853|
| Emax [lx]                   | 21.618 | 24.909| 27.382    | 30.245| 33.147|
| g1                          | 3.60   | 4.68 | 5.76      | 5.24| 5.16|
| g2                          | 0.508  | 0.475| 0.447     | 0.42| 0.40|

**Figure 8.** Illuminance distribution index.
The amount of electricity costs incurred for the PJU redesigned results is Rp. 709,929 for 1 month and Rp. 8,519,148 in 1 year. From these results it can be seen that the electricity cost of the redesigned PJU is more efficient by 58.6% per month compared to the existing PJU. The cost reduction can occur due to the use of different types of lamps than those already installed using SON type lamps and the results of optimization using LEDs that have lower power and higher efficiency.

4. Conclusions
The resulting design uses a combination of the application of Mamdani fuzzy logic and DIALux software can produce the desired lighting system and in accordance with SNI. The redesign results have both power and cost savings of 58.6% from existing conditions, where the total power used in one month existing conditions is 3.25 kW and the amount of electricity costs in one month is Rp.1,716,717 while the results of the design repeated total power used in one month that is 1,344 kW and electricity costs in one month is Rp.709,929.

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