Application of Genetic Algorithm in optimizing redesign of street lighting

R Shintabella*, A G Abdullah and D L Hakim
Department of Electrical Engineering Education, Universitas Pendidikan Indonesia, Jalan Dr. Setiabudhi 207, Bandung 40154, Indonesia

*rosenasbella@student.upi.edu

Abstract. Street lighting system is designed to give comfort to users by considering the energy saving aspect, lighting quality and suitability with the lighting standard. This research aims to describe the results of optimizing the redesign of street-lighting using the artificial intelligence method, Genetic Algorithm. This algorithm is applied based on the relationship between energy use and public street lighting parameters such as the average illumination, wide roads, high pole, and various other parameters that correspond to the lighting standards in Indonesia. The redesign process is using MATLAB for Genetic Algorithm simulation and DIALux for implement of design results. The results of this study indicate that this method is very good and recommended to the designer in determining the design parameters.

1. Introduction
Street lighting is one of the important facilities in urban development [1,2]. It has functions such as reducing crime rates and increasing road user safety at night [3]. Specifically, in densely populated areas, many people walk and drive at night to move. Interactions between people at night can increase economic vitality and stimulate investment [4]. The good and constant of quality lighting can increase the safety and comfort of road users. The quality of street lighting can be seen from several factors such as equalization, lighting adjustment, radiation reduction and environment friendly [5]. But to produce lighting with good quality requires a lot of energy. As such, designs with methods that make it possible to obtain quality and energy savings in general street lighting are discussed in recent research [6].

In general, the criteria for street lighting design are the level of lighting and consideration of several aspects such as safety, energy consumption, and economics [7]. In the design of street lighting installation optimization methods are needed to obtain ideal results. Many development methods are used for optimization of street lighting design, one of which is the artificial intelligence approach namely Evolution algorithm which works effectively in the case of street lighting design optimization [8]. Previous studies using evolution algorithm with multi-objective optimization can provide design solutions that optimize certain lighting parameters. For multi-objective evolution algorithms two optimized parameters can be applied namely energy efficiency and lighting uniformity where the lighting level matches the recommended value for the type of street lighting [9]. Genetic algorithm is the part of evolution algorithms that can adaptively solve a search for value in optimization problems.

The research is focused on getting the procedure more accurate and simpler to plan the installation of energy-saving lighting solutions for street lighting design. The method used is the Genetic
Algorithm to achieve maximum energy efficiency. This method has been used successfully in various continuous optimization problems by providing solutions to complex problems on the basis of the theory of evolution [10]. MATLAB and DIALux software will be used in this research. With this software, this research is expected to produce designs that are in accordance with Indonesian National Standards (SNI).

2. Research methods
The object of this study is one of the roads in the city of Bandung, Indonesia (Fig. 1) with data obtained from the results of measurements in 2019 on the study area road which is the result of the Bandung street lighting evaluation project by the Department of Electrical Engineering Education and the Bandung City Bina Marga Office. 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 study area road is 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) length 598 m, width 15 m, and 13 poles. The type of street lighting used is single row (one side) with a 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 complete procedure in this study is shown in Fig. 2.

2.1. Data processing method
In this study the instruments used are MATLAB R2016b and DIALux evo 9.0 which aimed to optimize design using Genetic Algorithm and implementation of street lighting design results of optimization. MATLAB R2016b will be used for Genetic Algorithm simulation for the best street lighting design optimization. DIALux evo 9.0 functions to implement the results of the optimization of
Genetic Algorithms through redesign of public street lighting. After the data has been collected, this research design is planned to go through several stages as follows:

- Looking for street lighting data to be used as input material for Genetic Algorithm.
- Conduct secondary data collection: road characteristics in the study area such as road width, sidewalks, pole height, average illuminance, type of lamp used etc.
- Processing data for Genetic Algorithm input that will be used in redesign optimization.
- Perform a design optimization simulation using Genetic Algorithm Using MATLAB (Fig. 3).
- Implement the design using the DIALux.
- Processing design data to find out the use of electrical energy.

2.2. Simulation using genetic algorithm

Fig. 3 is the first step in solving a problem with a Genetic Algorithm coding the problem to be solved. The breeding cycle begins with the creation of a random set of solutions called populations. Where there are individuals called chromosomes. This chromosome is slowly "iterated" in a generation. The steps to create the next generation of offspring can be done by combining the two chromosomes that have been obtained with a crossover or mutation operator. A new generation before being evaluated again, it will go through a selection process based on the fitness function.

In Genetic Algorithm the fitness function must be designed according to each problem to be solved. From this creation the most fit chromosomes are most likely to be selected. Genetic operations (crossover and mutation) work in the coding area, while the evaluation process and selection process work in the solution area. After several generations, this algorithm will converge on the best chromosome which is the optimum value of the problem being solved.

![Simulation Procedure Diagram](image)

**Figure 3.** Simulation procedure.

3. Results and discussion

This research uses the artificial intelligence method, which is the Genetic Algorithm approach. This method works in the search for optimum results based on the mechanism of natural selection and the theory of evolution. Optimization is carried out in several stages in accordance with the provisions of the Genetic Algorithm in maximizing the quality of lighting and saving energy in street lighting. The configuration used is the aspects needed by the street lighting in accordance with the provisions of SNI. The use of the DIALux application in this study is as an implementation of the design optimization results. Knowing the condition of the existing street lighting in the study area is very important because it will determine the feasibility of a redesign or not.

The object of this research is one of the roads that has a high density level during the day and night because around the road there are public facilities such as hospitals, vehicle repair shops, hotels and is an access to get to the Bandung city train station. Close to the city centre and being a link between regions within the city makes this road has a high level of density. The study area's street lighting has 13 lighting points with different conditions on each pole. Ideal conditions with uninterrupted poles can be seen in Fig. 4(a), these conditions are very good for spreading light. In this condition the light emitted by street lighting will immediately spread to the object without any obstructions that can affect the value of the illumination. As for Fig. 4(b) is an example of a pole with no ideal conditions because it is covered with trees which causes the spread of light to be less than optimal, it can even be worth 0 lux for the level of illumination. Such conditions are found in the study area street lighting, the light emitted by the street lighting does not directly spread to the object because it is blocked by external factors such as trees.
Figure 4. Condition of street lighting in study area: (a) Ideal conditions, namely lighting 6 and 8, (b) Conditions not ideal, namely lighting 4 and 5.

According to SNI 7391: 2008 the level of evenness of light on the type of primary collector road is 3-7 lux. The average illumination of the study area's street lighting meets SNI at 4.57 lux, but it has poor lighting. Although the average illumination value is in accordance with SNI, there is still lighting that is blocked by external factors such as trees, so the illumination value is very small. There are 25% of the 13-study area street lighting points that have below average illumination rates. The illumination value is 16.7% which is close to the average and 41.7% in accordance with SNI. There are also illuminations that are greater than the average SNI of 16.7%. Internal factors such as the age of the lamp used make the illumination different for each lamp and external factors such as external light can affect the average illuminance of the study area's street lighting. The correlation between street lighting and the number of vehicles passing through the road is basically related to lighting [11]. Conversely, when street lighting is too dark it will be very dangerous for road users, especially pedestrians. Threats of crime such as robbery, theft and mugging are examples of criminality that can occur on dark roads.

3.1. Optimization of genetic algorithms and design implementation

Optimization is done by using the Genetic Algorithm approach, with 10 Number of Genes (NumGen) which is the number of genes in one chromosome, 100 population sizes (PopSize) which is the number of population to be formed, the cross probability (Pcross) that will be used in the crossover value 0.8 in accordance with the provisions of the TSP method, the Pmutation to be used in the mutation process is valued according to the TSP method provisions, and a maximum of 100 genes (MaxGen) is the maximum number of genes formed in a population. Population is a group of individuals that contains chromosomes and genes. This study uses 10 populations that contain provisions on street lighting (Table 1).

| The design | Lamp Power | Light Placement Provisions | The width of the road | Average Lighting | Pole Height | Luminous Efficacy |
|-----------|------------|-----------------------------|-----------------------|------------------|------------|-----------------|
| 1         | 128 Watt   | 1 (one-side) / 2 (coupled/staggered) | 15 m                 | 7 Lux           | 10-15 m    | 110-120 lm/w     |
| 2         | 90 Watt    | 1 (one-side) / 2 (coupled/staggered) | 15 m                 | 7 Lux           | 10-15 m    | 110-120 lm/w     |
| 3         | 81 Watt    | 1 (one-side) / 2 (coupled/staggered) | 15 m                 | 7 Lux           | 10-15 m    | 110-120 lm/w     |
| 4         | 60 Watt    | 1 (one-side) / 2 (coupled/staggered) | 15 m                 | 7 Lux           | 10-15 m    | 110-120 lm/w     |
| 5         | 42 Watt    | 1 (one-side) / 2 (coupled/staggered) | 15 m                 | 7 Lux           | 10-15 m    | 110-120 lm/w     |
3.1.1. Evaluation (fitness function). The fitness function in this design implements the maximum fitness function to find design solutions by minimizing energy use. The minimum fitness function can be found by the equation below:

\[
\text{Fitness Function} = \frac{1}{\text{objective function} + \text{Small Number}}
\]  

(1)

The objective function used is the following equation:

\[
\text{Purpose Function} = \text{norm}(\text{XYstreet}(\text{chromosome}(ii,:) - \text{XYstreet}(\text{chromosome}(i + 1,:)))
\]  

(2)

Information:

Norm = functions that are available in MATLAB

XYstreet = \{1 1.22; 1 0.86; 1 0.77; 1 0.57; 1 0.4; 2 2.44; 2 1.71; 2 1.54; 2 1.14; 2 0.78\}

Chromosome (ii) = chromosome to .... (if ii + 1 then the chromosome number increases by 1)

XYstreet used is obtained from the following equation:

\[
f(S,k) = f(X,Y)
\]  

(3)

k is a coefficient with two possible values: k = 1 (if one-sided luminaire arrangement) or k = 2 (if the arrangement is two-sided or alternating) and S is the following equation:

\[
S = \frac{k \times P}{\omega \times E}
\]  

(4)

Information:

P = Electric power consumed by street lighting

\(\omega\) = Road width

E = Provision of average illuminance

From the equations above, the best fitness value is the population fitness value of 10 chromosome 6 which is equal to 0.1950. While the worst fitness value is the fitness value of population 5 chromosome 4 which is 0.0854. The population with the best fitness value will become parents in the crossover process, because they are able to stay alive when individual selection takes place. Conversely, when populations with poor fitness scores are eliminated when individual selection takes place.

3.1.2. Individual selection (roulette-wheel). Individual selection Chromosome 6 in population 10 (P10 K6) occupies the largest cut position at 14%, followed by chromosome 3 in population 9 (P9 K3) with a cut of 12%. While the smallest slice is occupied by chromosome 4 in population 5 (P5 K4) with a cut of 6% (Fig. 5). This makes P10 K6 and P9 K3 will remain alive in the next process, while P5 K4 will be selected so that they cannot survive in the next process.

![Figure 5. Individual selection results.](image-url)
3.1.3. Genetic algorithm results

After going through several processes, the best design for the street lighting in the study area will be obtained (Fig. 5). The best design is the population with the best fitness value and has gone through the process of structural recombination (crossover and mutation).

![Figure 6. Simulation results from genetic algorithm.](image)

In Fig. 6 the curve shows the fitness values of all generations, with the best fitness of 0.195037; average fitness value of 0.122904; population size is 100 with a mutation probability of 0.005. The table in the figure above states that the most optimal electric power for use in the study area is 42 watts, with a two-sided or alternating luminaire arrangement coefficient, a recommended mast height of 10 m and a luminous efficacy of 120 lm/watt. From the results of optimization, all the best design recommendations fulfill SNI standards.

The Genetic Algorithm approach is a very quick and easy method for planning street lighting installations by ensuring maximum energy saving aspects and producing good uniformity of light. This method is very effective to be used to make it easier to calculate the main parameters in a street lighting installation. Optimization using this approach will provide a fast method for designing sustainable installations for both street lighting and other lighting [12].

3.2. Implementation of street lighting design using DIALux

From the results of design optimization using the Genetic Algorithm method the best design recommendations are obtained for the study area road with the following specifications:

| The design | Lamp Power | Light Placement Provisions | The width of the road | Average Lighting | Pole Height |
|------------|------------|-----------------------------|-----------------------|------------------|-------------|
| 42 Watt    | 2 (coupled/staggered) | 15 m | 7 Lux | 10 m | 120 lm/w |

Based on Table 2, the lamps chosen are Philips BGP322 T35 1XGRN78-3S / 740 DW with specifications close to the terms of the optimization results of electric power of 42 watts, luminous efficacy of 119 lm / watt, and luminance of 5500 lm with 91% LOR (Fig. 7).
After the lamp and all parameters are fulfilled, DIALux will automatically display the average value of the illumination. The average illumination value of the redesigned street lighting was 6.15 lux with an evenness ratio of 0.54. To illustrate the spread of light can be seen in Fig. 8. From the results of the illustration of the spread of light, the colour blue looks dominant among other colours. The blue colour is an illustration of 5-10 lux illumination level, the green colour is an illustration of 0-5 lux illumination, and the red colour is an illustration with 10-15 lux illumination level. This dominant blue and green colour reflect the level of illumination according to SNI, which is 0-10 lux with an average overall illumination level of 6.15 lux. For comparison of the value of existing street lighting illumination with the redesigned street lighting results of optimization using Genetic Algorithm can be seen in Table 3.

| Lighting Type                  | Existing street lighting | Optimized street lighting | SNI     |
|-------------------------------|--------------------------|---------------------------|---------|
| E Average (Street)            | 7.13 Lux                 | 6.15 Lux                  | 3-7 Lux |
| E Average (Right sidewalk)    | 7.17 Lux                 | 3.24 Lux                  | 3-7 Lux |
| E Average (Left sidewalk)     | 4.68 Lux                 | 3.03 Lux                  | 3-7 Lux |

This comparison uses the data is 1 point of street lighting, for existing data is street lighting number 8 with ideal conditions because the spread of light is not disturbed by external factors. From Table 8 the average value of existing street lighting illumination for right roads and sidewalks is close to SNI but does not meet the standards while for the left sidewalk meets SNI. For the lighting of the redesign road, the results of optimization Genetic Algorithm are the average illumination for the road, the right sidewalk and the left sidewalk fulfil SNI.

### 3.3 Electric energy
Based on the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 28 Year 2016, the group of electricity tariffs for the purposes of street lighting at
low voltage is the P-3 / TR type. Then the usage fee is 1,467.28 (Rp / kWh). Electricity costs in road lighting can be calculated using equations 5 and 6, with the results of the comparison listed in Table 4.

\[
\text{Electricity energy tariff} = W \times \text{asic electricity tariff} \quad (5)
\]

\[
W = P \times t \quad (6)
\]

Information:
\[
W = \text{electrical energy (kWh)}
\]
\[
P = \text{electrical power (kW)}
\]
\[
t = \text{how long the lamp operates (t)}
\]

| Table 4. Comparison of energy usage. |
|--------------------------------------|
|                                      |
| **Existing street lighting**         | **Optimized street lighting**   |
|--------------------------------------|--------------------------------|
| Total electric power                 | 3.25 kW                         | 1.05 kW                        |
| Electricity energy rates (1 month)   | Rp. 1.716.717                   | Rp. 554.632                    |
| Electricity energy rates (1 year)    | Rp.20.886.730                   | Rp. 6.748.021                  |

In this research, optimization of street lighting design using the Genetic Algorithm method is proven to be able to save energy. This design managed to save energy up to 32% with a cost of 70% more savings in 1 year. This is caused using LED technology with low power but has a high level of illumination. This design is also proven to be good in terms of evenness of light that can be seen from the results of implementation using the DIALux application. Energy consumption in street lighting systems is possible using LED technology because this type has better light quality with low light pollution [13]. Therefore, although LED may require more investment budget, it can be considered more effective compared to HPS in monthly expenditure budgets. [14]. LED technology as a substitute for conventional lighting has been chosen because it promotes significant efficiency.

4. Conclusions

The condition of the general street lighting in the study area has not fulfilled SNI 7391: 2008, although the average illumination has met the standard type of primary collector road but the light distribution is still not good which causes this road to be redesigned. In this study the results of the optimization using the Genetic Algorithm method produce the best design according to the standard criteria that apply in Indonesia. This design optimization can be proven by the implementation of DIALux which produces an average of illuminations in accordance with SNI 7391: 2008 with good evenness of light. The electricity consumed by public street lighting resulting from the optimization of Genetic Algorithms is 32% smaller with the cost of electricity being spent more economically by 68% (1 month) and 70% (1 year) from existing street lighting. The results of this study indicate that this method is very good and recommended to the designer in determining the design parameters for public street lighting.

References

[1] Abdullah A G, Pambudi R L, Purnama W, Nandiyanto A B D, Triawan F and Aziz M 2019 Redesigning street-lighting system using led and hps luminaires for better energy-saving application J. Eng. Sci. Technol. 14 2140–51
[2] Mohandas P, Dhararaj J S A and Gao X Z 2019 Artificial Neural Network based Smart and Energy Efficient Street Lighting System: A Case Study for Residential area in Hosur Sustain. Cities Soc. 48
[3] Bevish Jinila Y 2015 Solar powered intelligent street lighting system based on fuzzy logic controller Int. Rev. Electr. Eng. 10 399–403
[4] Kim D and Park S 2017 Improving community street lighting using CPTED : A case study of three communities in Korea Sustain. Cities Soc. 28 233–41
[5] Dolara A, Faranda R, Guzzetti S and Leva S 2010 Power quality in public lighting systems *ICHQP 2010 - 14th Int. Conf. Harmon. Qual. Power*

[6] Gutierrez-Escolar A, Castillo-Martinez A, Gomez-Pulido J M, Gutierrez-Martinez J M, Stapic Z and Medina-Merodio J A 2015 A study to improve the quality of street lighting in Spain *Energies* **8** 976–94

[7] Beccali M, Bonomolo M, Lo Brano V, Ciulla G, Di Dio V, Massaro F and Favuzza S 2019 Energy saving and user satisfaction for a new advanced public lighting system *Energy Convers. Manag.* **195** 943–57

[8] Rabaza O, Peña-Garcia A, Pérez-Ocón F and Gómez-Lorente D 2013 A simple method for designing efficient public lighting, based on new parameter relationships *Expert Syst. Appl.* **40** 7305–15

[9] Gómez Lorente D, Rabaza O, Espin A and Peña García A 2013 Optimization of Efficiency and Energy Saving in Public Lighting with Multi-Objective Evolutionary Algorithms *Renew. Energy Power Qual. J.* **1** 62–5

[10] Gómez-Lorente D, Triguero I, Gil C and Espin Estrella A 2012 Evolutionary algorithms for the design of grid-connected PV-systems *Expert Syst. Appl.* **39** 8086–94

[11] Ciobanu I 2016 Analysis on the Possibility of Using Retrofit Solutions for Increasing the Energy Efficiency of Public Lighting Systems 0–4

[12] Rabaza O, Gómez-Lorente D, Pozo A M and Pérez-Ocón F 2019 Application of a Differential Evolution Algorithm in the Design of Public Lighting Installations Maximizing Energy Efficiency *LEUKOS - J. Illum. Eng. Soc. North Am.* **00** 1–11

[13] Jp O and Nagai H 2013 (12) United States Patent 2

[14] Bergesen J D, Tähkämö L, Gibon T and Suh S 2016 Potential Long-Term Global Environmental Implications of Efficient Light-Source Technologies *J. Ind. Ecol.* **20** 263–75