Optimization of school location-allocation using Firefly Algorithm

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Abstract. The zoning policy of Indonesia New Student Admission System encourages schools to accept more students from their zoning location. This condition needs to be supported by a good management to ensure that the school facilities suffice the student distribution. School location-allocation optimization problem aims to obtain optimum student distribution such that the total of students travel distance is minimized. This problem is modeled as p-median problem, and can be solved using meta-heuristic approach. In this study, firefly algorithm with two-dimensional firefly individual representation is utilized to solve South Jakarta junior school location-allocation problem. The obtained solution lowers 57.58% of student travel distance compared to the previous condition assuming that favorite schools are tend to be chosen by students.

1. Introduction
Zoning policy of Indonesia New Student Admission System (Penerimaan Peserta Didik Baru) (PPDB) requires students to choose schools located in the same zone as their residence [1]. This policy is intended to reduce students traveling distance and encourage equal distribution of school quality. Management of student allocation to schools based on zoning policy is needed to encourage effectiveness and prevent inefficient use of facilities.

School location allocation problem aims to optimize a number of students to be served by a number of schools. The allocation sometimes also considers a number of certain constraints. This kind of facility location problem is widely modeled by p-median approach, which is a model of locating p number of facilities in order to minimize the weighted average distance between demand nodes and the chosen facility [2]. P-median problems are commonly solved using heuristic and integer programming approach [3, 4, 5, 6, 7]. However, p-median problems can also be solved using meta-heuristic approach. It is a solution strategy that focus the search in local region while trying to generate diverse solutions to explore the global search space [8]. Meta-heuristic tries to improve the search coverage at each iteration so that the algorithm converges to near optimum value [9]. This research aims to solve school location-allocation problem using firefly algorithm, which is one of the well-known meta-heuristic approach.

2. Problem Formulation
In 2017, the demand population for South Jakarta junior public school is 44,003, which is calculated based on the number of population aged 13-15, with 95.8% school participation rates and 58.21% public schools population ratio [10]. South Jakarta consists of 65 junior public
schools spread across 65 urban villages in 10 sub-districts. Considering the PPDB zoning policy, optimization of school location-allocation is done by distributing students to schools based on their zone location. This way, the optimization aims to provide allocation with minimum total travel distance. Using assumption that students live in the center of urban villages, the total of student travel distance can be formulated as follows.

\[
TravelDistance = \sum_{i=1}^{M} \sum_{j=1}^{N} a_{ij}d_{ij}z_{ij}
\]  

Subject to

\[
\sum_{i=1}^{M} a_{ij}z_{ij} = P_j
\]

\[
\sum_{j=1}^{N} a_{ij}z_{ij} \leq Q_i
\]

Where

- \( M \) represents number of schools
- \( N \) represents number of urban villages
- \( a_{ij} \) represents number of students from urban village \( j \) allocated to school \( i \)
- \( d_{ij} \) represents distance between school \( i \) and urban village \( j \)
- \( z_{ij} \) represents zoning status between school \( i \) and urban village \( j \)
- \( z_{ij} = 1 \) if school \( i \) and urban village \( j \) are in the same zone, \( z_{ij} = 0 \) otherwise
- \( P_j \) represents demand of junior public school in urban village \( j \)
- \( Q_i \) represents maximum capacity of school \( i \)

Constraint (2) is hard constraint while constraint (3) is soft constraint that need to be considered. Constraint (2) requires that the total number of students from urban village \( j \) allocated to each school is equal to the number of student population of urban village \( j \). Constraint (3) represents that the total number of student allocation in each school cannot exceed the school capacity.

Before zoning policy, favorite schools tend to be chosen. In this study, favorite schools of South Jakarta are assumed to be located at the center of regency. Assuming that students from each urban village will be distributed to favorite schools, the travel distance for this condition is about 222,857 km.

3. Methodology
Firefly Algorithm (FA) is one of meta-heuristic, swarm intelligence optimization algorithms. Developed by Xin-She Yang in 2008, FA is inspired by the flashing behavior of fireflies [9]. Although it was originally designed to solve continuous optimization problem, FA can be discretized to solve permutation problems, such as Traveling Salesman Problem (TSP) [11] and job shop scheduling problem [12].

FA is based on the communication behavior of fireflies. Fireflies produce short and rhythmic flashes whose pattern is often unique for particular species. These flashes are for attracting either mating partner or potential prey. FA uses the following three idealized rules [9]:

- Fireflies are unisex, hence they will be attracted to other fireflies regardless of their sex;
- Attractiveness is proportional to the brightness, hence the less brighter firefly will move towards the brighter one;
- The brightness is determined by the value of the objective function.
Figure 1. Process flow of firefly algorithm

FA is population-based algorithm. In FA, a number of fireflies is randomly generated as solution initialization. Every firefly has a position that represents its brightness. Each firefly will go through the comparing and moving process for a number of iterations. At the end of iterations, the brightest firefly will be chosen as solution. The flow of FA is shown in Fig. 1.

3.1. Firefly Representation
In this study, two-dimensional firefly representation is utilized. An individual firefly $f$ is encoded as $M \times N$ matrix, where $M$ represents the number of schools and $N$ represents the number of urban villages. Each element $f_k(i,j)$ represents the number of students at urban village $j$ allocated to school $i$, with $1 \leq i \leq M$ and $1 \leq j \leq N$.

3.2. Light Intensity
Light intensity represents the brightness of a firefly, which is determined by the objective function of the problem. The higher the light intensity, the more likely it will be chosen as the suitable solution. Since the objective in this study is to minimized the student travel distance, the light intensity is inversely proportional to the objective function shown in formula (1). Based on this rule, the light intensity $I$ can be formulated as follow.

$$I = \frac{1}{TravelDistance}$$ (4)
3.3. Distance
Distance describes how close the relationship between two fireflies. In continuous optimization problems, distance between two fireflies is simply calculated using Euclidean distance formula. In school location-allocation problem with two-dimensional firefly representation, the distance between two fireflies is represented by the element-wise matrix difference. In other words, the distance between two fireflies can be seen as the distance between each matrix element in position \((i, j)\). Distance between firefly \(A\) and firefly \(B\) is simulated in Fig. 2.

3.4. Attractiveness
Attractiveness value determines how strongly a firefly affects other fireflies. Attractiveness is proportional to the light intensity seen by adjacent fireflies. This means that the distance between adjacent fireflies affect the value of attractiveness. In the problem of school location-allocation with two-dimensional firefly representation, the distance between two firefly is seen as the element-wise distance between the two firefly matrices. Therefore, attractiveness is represented in matrix and the calculation is performed on each matrix element as formulated bellow.

\[
\beta(i, j) = \frac{\beta_0(i, j)}{1 + \gamma r_{(i,j)}}
\]

Where
- \(\beta_0(i, j)\) represents attractiveness matrix element value at position \((i, j)\) at zero distance
- \(\beta(i, j)\) represents attractiveness matrix element value at position \((i, j)\) at \(r\) distance
- \(r_{(i,j)}\) represents distance between two firefly matrix elements at position \((i, j)\)
- \(\gamma\) represents light absorption parameter

3.5. Light Absorption
The light absorption parameter \(\gamma\) characterizes the variation of attractiveness. It determines the speed of convergence and how the FA algorithm behaves [9]. In theory, \(\gamma \in [0, \infty)\), but in practice, the value of \(\gamma\) is determined by the problem characteristic. For most applications, it typically varies from 0.1 to 10.

3.6. Movement
Movement is the process of updating the position of a firefly towards the brighter one. The purpose is to find a new position that is expected to increase its light intensity. Movement of firefly \(A\) towards firefly \(B\) is affected by attractiveness value and is formulated as follow.

\[
f_A = f_A + \frac{\beta_0}{1 + \gamma r_{AB}^2} (f_B - f_A) + \alpha \epsilon_A
\]

\[\text{Figure 2. Distance between two fireflies.}\]
Where $f_A, f_B$ represents matrix for firefly A and firefly B.

The term $\alpha \epsilon_A$ is a randomization factor, with $\alpha$ being the randomization parameter, and $\epsilon_A$ is a matrix of random numbers drawn from Gaussian or uniform distribution.

4. Experimental Results

The proposed algorithm was implemented in Python and run on an Intel Core-i5 PC with 4GB RAM. Table 1 shows the summary of experimental parameters and results. There were 50 solutions obtained through 50 number of running. For each running, population size 20 and maximum iterations 200 is used. The average running time is about 376 seconds. The minimum travel distance is 94,529.522337 and the maximum travel distance is 98,381.956173, while the average travel distance of all solutions is 96,513.554613. Comparing the travel distance without zoning policy, i.e. 222,857 km, and the minimum travel distance obtained from the proposed algorithm, i.e. 94,530 km, we obtained the total reduced travel distance is 128,327 km or 57.58%.

| Parameter                  | Value                      |
|---------------------------|----------------------------|
| Number of running         | 50                         |
| Population size           | 20                         |
| Number of iterations      | 200                        |
| $\beta_0$                 | 1                          |
| $\gamma$                  | 0.05                       |
| $\alpha$                  | 0.05                       |
| Average running time      | 376.178519998              |
| Minimum travel distance   | 94,529.522337              |
| Maximum travel distance   | 98,381.956173              |
| Average travel distance   | 96,513.554613              |

Fig. 3 shows the value of best light intensity obtained at each iteration. It can be seen that during the iterations, the intensities are increasing over time. This proves that the movement approach is suitable to FA behavior. It also shows that in FA, each firefly moves towards the optimum solution value in a certain convergence rate.

5. Conclusion

In this study, firefly algorithm with two-dimensional individual representation approach is utilized to solve school location-allocation problem of South Jakarta public schools. The FA program was run for 50 times and the firefly with maximum light intensity was chosen as the optimum solution. The obtained solution lowers the student total travel distance by 57.58% compared to allocation condition which assumed that students tend to choose favorite schools located in the center of regency.

In the future work, considering school capacity as one of the hard constraints could be done to improve the proposed FA. Furthermore, different meta-heuristic or parameter tuning approach can be applied to examine the applicability of the proposed FA. Comparing the obtained result with the real student allocation in South Jakarta can also be done as improvement.
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Figure 3. Best light intensity obtained at each iteration.