Preparación de Artículos revista VISIÓN ELECTRÓNICA: algo más que un estado sólido
Fecha de envío: 5 de enero de 2021
Fecha de recepción:
Fecha de aceptación:

Firefly algorithm for facility layout problem optimization

Algoritmo Luciérnaga para optimización de layout de distribución en planta

Luisa Fernanda Vargas pardo* Frank Nixon Giraldo Ramos **

Abstract: This paper shows the result of a research about the applications of bio-inspired algorithms in the field of production engineering in the Distrital University Francisco José de Caldas, covering the topics of industrial layout distribution in manufacturing plant layout. It is intended to seek the optimization of some problems of those fields, using artificial intelligence from the implementation of a firefly algorithm as metaheuristic planning tool and optimization of layout problem. With the goal of finding the best spatial allocation of work stations or cells. Theoretical concepts explored and results are presented.

First, a state-of-the-art review on the subject was made, and then the possible solution algorithms were evaluated to identify the objective function to be optimized, to finally apply the firefly algorithm, and evaluate the results of performance against the Initial layout as the plant.

Keywords: Facility Layout Problem, firefly optimization, metaheuristics, combinatorial optimization

Resumen: Este trabajo muestra el resultado de una investigación sobre las aplicaciones de los algoritmos bioinspirados en el campo de la ingeniería de producción en la Universidad

* Estudiante de Ingeniera en Producción, Universidad Distrital Francisco José de Caldas, Colombia. Facultad Tecnológica, e-mail: lfvargasp@correo.udistrital.edu.co
** Docente de planta Universidad Distrital Francisco José de Caldas, Colombia. Facultad Tecnológica, e-mail: fngiraldor@udistrital.edu.co

Distrital Francisco José de Caldas, abarcando los temas de distribución de layout industrial en planta de fabricación. Se pretende buscar la optimización de algunos problemas de dichos campos, utilizando la inteligencia artificial a partir de la implementación de un algoritmo de luciérnaga como herramienta metaheurística de planificación y optimización del problema de layout. Con el objetivo de encontrar la mejor asignación espacial de los puestos de trabajo o celdas. Se presentan los conceptos teóricos explorados y los resultados obtenidos.

Primero se hizo una revisión del estado del arte sobre el tema, y luego se evaluaron los posibles algoritmos de solución para identificar la función objetivo a optimizar, para finalmente aplicar el algoritmo de la luciérnaga, y evaluar los resultados de desempeño frente al layout Inicial como la planta.

Palabras clave: Problema de disposición de instalaciones, optimización firefly, metaheurística, optimización combinatoria

1. Introduction

The plant layout problem is a way of get an optimal design of the location and flexible configuration of machines, equipment, resources, physical space available, to facilitate the movement and handling of material and enable the plant to have a performance and production flow optimized, all under a minimum production cost and total time [1]. Traditionally, the study of such problems of distribution and spatial flow and optimization, has been addressed by dynamic programming techniques and combinatorial optimization [2] [3] and in operations research [4] and is often called "Facility Layout Problem - FLP ".

In this optimization goal, the firefly algorithm will be applied, which is inspired by the intermittent and rhythmic light behavior of fireflies, which are winged insects capable of producing flashes of light to attract possible prey or their companions. They are like a capacitor operation, charging slowly until a certain threshold is reached, which when reached allows them to release energy in the form of light, after which the cycle repeats. In the firefly algorithm, a population of fireflies is placed at random locations in the search space where the fireflies represent a candidate solution. Firefly flashing light is formulated in such a way that it is associated with the target function to be optimized [5].

This algorithm was introduced in 2009 by Xin-She-Yang [6], who idealized some of the characteristics of the light flicker of fireflies. Based on the following three rules:

- All fireflies are unisex, so that each firefly is attracted to the others regardless of their gender.

- The degree of attraction is proportional to its brightness, therefore, for any two blinking fireflies, the one with the lowest brightness will move towards the brighter one. The degree of attraction is proportional to the brightness which decreases as its distance increases. If none are brighter than a particular firefly, they will move randomly.

- The brightness of a firefly is affected or determined by the objective function.

The layout optimization problem corresponds to a traveling agent problem, symmetric, uni-objective and Euclidean [7].

When configuring the layout of a plant, it is like a performs a movement in the XY plane. The total travel time can be determined as the time to travel the process flow path on the layout plus the time at each station:

$$t = nt_m + t(x, y)$$

where n is the number of workstations, t_m the operation time per station, and t (x, y) the time to execute the process flow path on the layout. The objective is to optimize the path followed by the process throughout the layout t (x, y), and therefore the cost of operation. This implies optimizing the flow of the process on the layout. Where the distance between two workstations, i and j of the layout is considered rectilinear and corresponds to the Euclidean distance of the two points with coordinates (x_i, y_i) and (x_j, y_j) respectively can be calculated as:

$$d_{ij} = |x_i - x_j| + |y - y_j|$$

The equation to calculate the flow of the process on the layout plane XY to move from a point i to a point j is a problem similar to that of the traveling agent. In such a way that, the distance of the route can be calculated by the equation:

$$t_{ij} = \frac{1}{v}\left(\sum |x_i - x_j| + \sum |y - y_j|\right)$$

$$t_{ij} = \left(\sum \frac{|x_i - x_j|}{v_x} - \sum \frac{|y - y_j|}{v_y}\right)$$

Where v_x and v_y correspond to the process flow displacement speeds in the directions x and and y respectively. The problem is simplified, v_x and v_y have the same value,$v_x = v_y = v$.

2. Methods:

This paper focuses on the application of firefly algorithm as a tool for solving combinatorial optimization problems, such as the facility layout problem in industrial manufacturing plant. With this goal, it has been proposed that many optimization algorithms, Firefly algorithm (FA) was first developed by Yang in 2007 (Yang, 2008, 2009) which was based on the flashing patterns and behavior of fireflies. [7] [12] [13]. In this case the optimization can be performed considering the following requirements including:

a. Minimizing material handling and its total distance between machines and layout stations.

b. Minimization of material flow.

c. Minimizing the total distance traveled by the material [5].

2.1. Firefly algorithm:

From the map of the layout that contains the (x, y) coordinates corresponding to the location of each of the nodes or workstations that are distributed on the plant, paths between nodes are defined, which conform a set of initial solutions that ants must optimizing in each cycle [5].

In the discretization of the firefly algorithm proposed by Kusuma and Suyanto (2011), a firefly represents a possible trajectory or path that gives an approximation to the optimal solution of the problem TSP, which is made up of a number of points or cities which they will be visited according to an order established by the movements of the fireflies. In the TSP, the function to minimize is the length of the layout flow, therefore the brightest firefly is the one with the shortest path length, which is given by the Euclidean distance between all the points or places visited.

The Firefly algorithm (FA) was originally designed to solve continuous optimization problems. However, for this case study, we will work in a discretized way to solve the permutation problem, such as the traveling agent problem. In order to adapt the firefly algorithm to solve this problem, it is necessary to implement the initial solution and distance functions x_i, x_j according to the TSP model. It is necessary to redefine the movements or movements of the fireflies, such as the search space, S_n, which includes all possible permutations {1, 2, …, n}.

In the case of optimization of maximization problems, the brightness I of a firefly at a location x can be noted as I (x) ∝ f (x). However, the degree of attraction β is relative; At the intensity of the glow that the other fireflies see. In this way, this varies as a function of the distance r{ij} between firefly i and firefly j. On the other hand, the intensity of light decreases with the distance from the source, in addition to being absorbed by the medium as well, in such a way that the degree of attraction also depends on the degree of absorption. Which means that the light intensity I (r) varies according to the inverse square law:

$$I(r) = \frac{I_s}{r^2}$$

where I_s, is the intensity of the light source. For a given medium with a fixed light absorption coefficient γ, the light intensity I varies as a function of distance r. So $I = I_0 e^{\gamma r}$, where I_0 is the original light intensity. In order to avoid singularity when r = 0 in the equation $\frac{I_s}{r^2}$, the effect of combining the absorption equation with the inverse square law can be approximated, using the following Gaussian form in which the intensity of light can be determined when the medium is known:

$$I(r) = I_0 e^{-\gamma r}$$

To avoid singularity at r = 0, the Gaussian equation can be approximated to:

$$I(r) = I_0 e^{-\gamma r^2}$$

Since each firefly has a degree of attraction β that can be described as a monotonically decreasing function of the distance r between any two fireflies:

$$\beta(r) = \beta_0 e^{-\gamma r^m}$$

Where β_0 denotes the maximum degree of attraction (when r = 0) and γ is the light absorption coefficient, which controls the decrease in light intensity as a function of distance.

The distance between two fireflies i and j at positions x_i

and x_j can be defined as:

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2}$$

Where xi, k is the k-th component of the spatial coordinate xi for the i-th firefly and d denotes the number of dimensions.

The movement of a firefly i can be determined as:

$$x_i = x_i + \beta_0 e^{-\gamma r^2{}_{i,j}}(x_i - x_j) + \alpha\left(rand - \frac{1}{2}\right)$$

Where the first term corresponds to the current position of the firefly i and the second term denotes the degree of attraction and the last term is used to generate a random movement, otherwise there is no firefly shining nearby (random is taken as a random number uniformly distributed in a range between {0,1}). α in (0, 1) is taken for all cases, and $\beta_0 = 1$. In practice, the light absorption coefficient γ varies between 0.1 and 10. This parameter describes the variation in the degree of attraction and is responsible for the speed of convergence of the firefly algorithm.

2.2. Objective function for evaluating the performance of tours:

All paths initially proposed, should be evaluated by an objective function to determine its quality and rate their degree of specific setting (fitness). Which consists, in this case, in the evaluation of the sum of each of the distances between nodes in the path, to determine the best paths sequences adapted according to their score. Then by the foraging, ants verify the quality of each path optimized in each cycle. With this purpose, the Euclidean distance objective function is proposed, as the sum of the distance between the coordinate points of the current node (x_i,y_i) and the next node (x_{i+1},y_{i+1}) to complete the all nodes or workstations forming the layout to obtain the total length of each of the raised paths:

$$dij = \sum_{i=1}^{n} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

Equation 1: Euclidian distance objective function

2. 3. Evaluation of the cost of each solution:

Heuristic information, called visibility is a function of the cost assignment. This cost can be represented by the flow and distances matrix.

$$d_{ij} = |x_i - x_j| + |y - y_j|$$

Equation 2: Heuristic information function

Where d_{ij} corresponds to the distance between nodes or cost objective function, in this case it corresponds to the Euclidean distance between points [22].

2.4. Stop criterion of the algorithm:

The Iteration of algorithm, using as criteria a maximum number of cycles and the cost coefficient or fitness, once this value is reached, the process ends, but not all cases can ensure that this solution is reached, but if it can achieve an optimized one.

3. Results

First, each firefly generates an initial solution at random; Parameters such as light intensity i, initial degree of attraction β_0 and light absorption coefficient γ are defined. So, every firefly, find the brightest firefly. If the brightness of one firefly is lower than the other, it will move to the next brightest. When a firefly moves its degree of attraction and intensity of light decrease. The best firefly will be chosen based on the objective function for the next iteration. This condition will be maintained until the maximum iteration is reached.

The following is the pseudo-code of the firefly algorithm:

1. Initialize the algorithm parameters: number of fireflies n,

coefficients α, β, γ maximum number of generations (iterations, Max-Gen).

Definition of the objective function f (x), $x = (x_1, \dots, x_d)^T$

Generation of the initial population of fireflies xi (i = 1, 2,..., N), Generation of n initial solutions, the light intensity Ii of the firefly at xi is calculated by the objective function f (xi).

2. While k <MaxGen

(k For $ i = 1: n For n fireflies)

For j = 1: n

If(Ij> Ii) moves the firefly i towards the firefly j according to the equation; The degree of attraction reached ends, according to its variation as a function of distance r according to equation:

$$t_{ij} = \frac{1}{v}\left(\sum |x_i - x_j| + \sum |y - y_j|\right)$$

New solutions are calculated and light intensity is updated

Loop end j

Loop end i

The best solution is taken

End while

3. Locate the firefly with the highest intensity of light.

For the discrete firefly algorithm, the distance between two fireflies i and j is the difference in the order of travel of the cities of the firefly i with respect to j, which is defined as distance Hamming.

This distance is determined as the number of times that the cities or coordinate points are not in the same position within their order.

Figure 1 shows, the plane of the floor of a machine shop, on which the path optimization is performed on an area of 123 x 60 meters, the nodes or sections that form are also indicated and the path must pass by them. Previously proposed algorithm was implemented as an m-file in Matlab script, the spatial coordinates (x,y) location of each station or node is entered as a vectors (x,y).

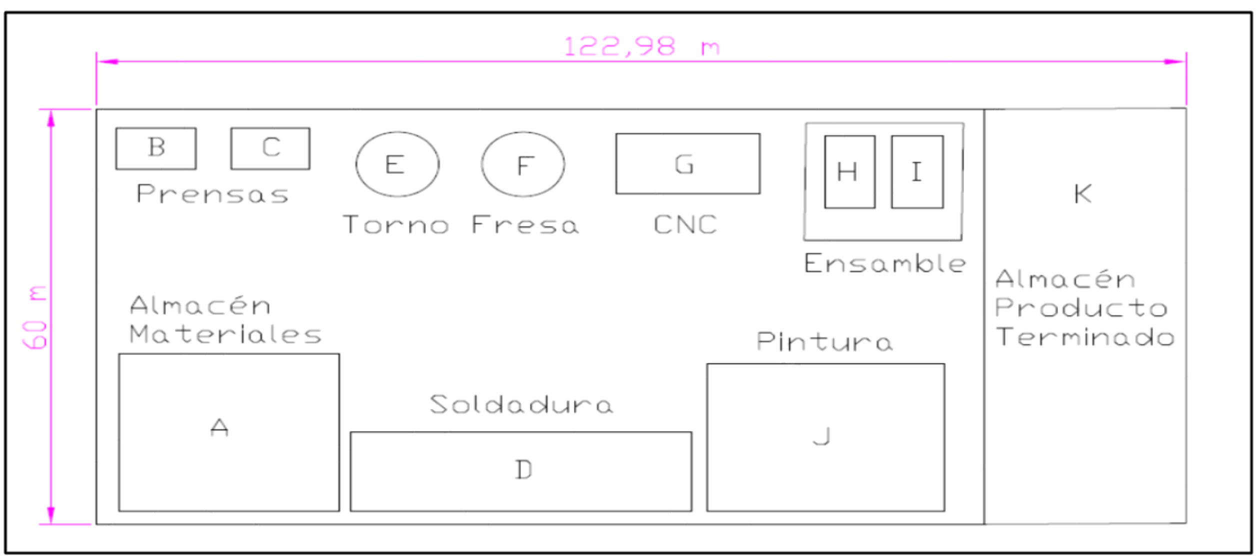

Figure 1. Coding sections and workstations on the layout.

Source: Authors

The total area where the plant is distributed is 7380 square meters. The total amount of monthly production is 1000 pieces and each piece currently covers a distance of 558.34 m to be finished.

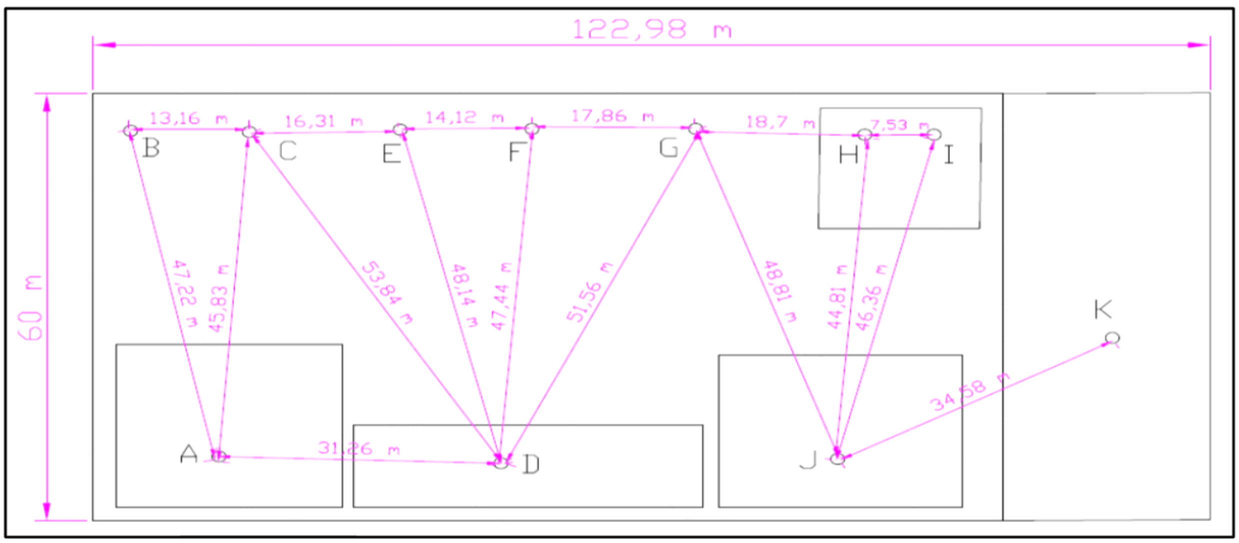

Figure 2. Initial paths distances in meters.

Source: Authors

The assumption on which the simulation was developed, was determined by the following considerations, the algorithm ends when 15 iterations or fitness value or less than the desired cost are achieved. The minimum number of fireflies should be at least equal to the number of nodes or workstations, which in this case was taken in 100. The weight parameters information at start was taken arbitrarily like α = 0.5, degree of attraction β = 0.1, light absorption coefficient

γ = 2, initial degree of attraction β_0 = 10. The number of best solutions groups was assumed equal to 25% of the number of fireflies.

Regarding the experimental application of the firefly algorithm in the layout optimization problem was implemented in Matlab version 2020 running on an Intel CORE i7 computer with 8 GB RAM, the same brightness function of the original firefly algorithm was used taking as m = 2.

To determine the value of the absorptivity coefficient, the attractiveness function is graphed, varying the distance rij and keeping β_0 = 10, This value of B is chosen arbitrarily, although in the experimentation phase it was observed that a very large value of this increases the simulation time drastically, and a very small value reduces the options in the search for an optimal solution. In the discretion of a firefly, the movements are carried out by permutation of the visit sequence as a subset of points or cities chosen at random by means of the random function, which is in charge of taking 2 positions randomly I and J, the positions between I and j form the subset that will be reordered. The probability that the firefly i or the j$ will be permutated or moved more times will be given by the brightness and the distance between fireflies as observed; in this way the solutions that give off less light are brought closer to those that give off a higher brightness.

A path is assigned to each ant k, from node i to node j, applying the formula of transitional probability. Ants repeat this process, until reach all the number of nodes initially set. Progressively evaluating the cost associated with each path to find the optimum value of cost or total distance in terms of iterations performed, see Figure 4.

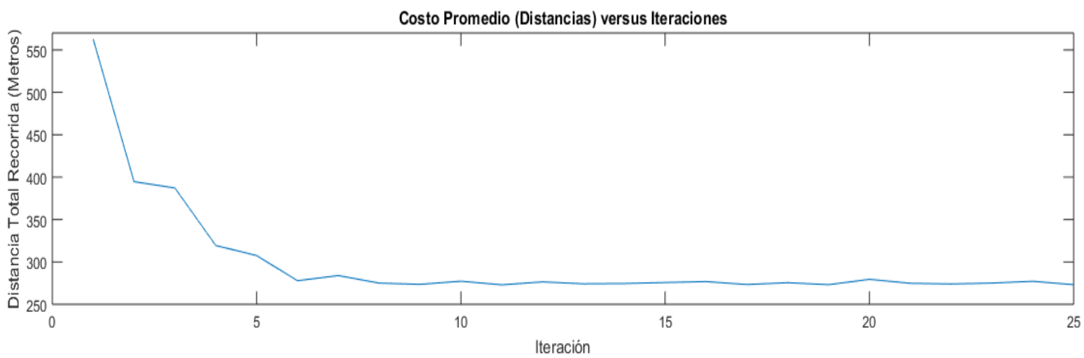

Figure 3. Cost curve optimization according to the iterations performed.

Source: Authors

After 15 iterations of the algorithm, the best found solution corresponded to the combination of Figure 4, with an associated cost of 271.93 meters. Compared with the initial configuration of the path that was at a value of 558.34 meters.

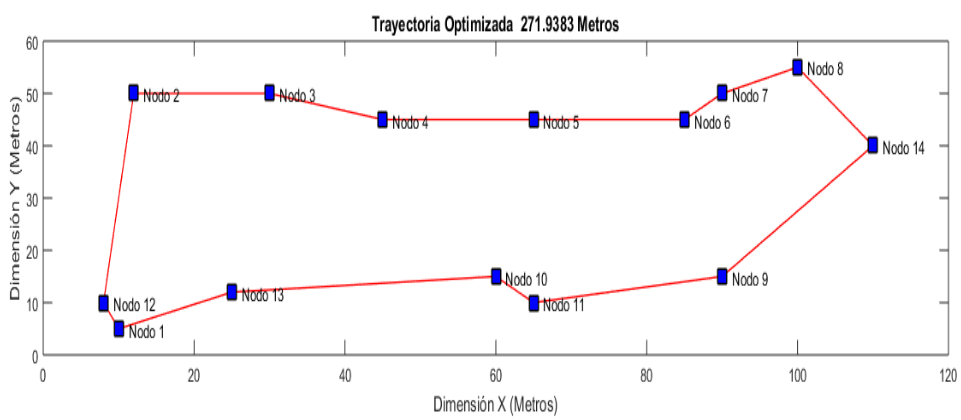

Figure 4. Optimized Tour. Source: Authors

4. Discussion

The costs associated with the layout management planning, depend among many aspects of the ability to optimize time, flows and handling of materials until a finished product. Under that premise, the scope of the results evidenced a final strategy for saving path but also the size optimization of material flow meter.

The unit costs are defined like paths in meters, to estimate the margins of the cost by path, so as to define production costs for each alternative. In each of the scenarios, it also minimizes the total production time. After completed the number of iterations for each simulation with the proposed scenarios, the cost calculations were performed to evaluate the best option and make decisions: the optimal solution from the point of view of operating costs.

5. Conclusions

The first consideration about firefly algorithm, defines a model or representation of the problem. It is important to define the objective function, taking into account to achieve greater fitness (fitness) and to have really and better solution for the given problem.

The initial value of the path without optimization, starts from an initial value of 558.34 meters, with the algorithm optimized a value of 271.93 meters was obtained like final value.

The firefly algorithm work particularly well solving combinatorial problems whose feasible solution space is too large to carry out a comprehensive search of reasonable time, as in this case optimization of paths and flows to plant layout.

It was evident, the potential of firefly algorithm in its implementation in logistic problems, as in the case of path planning, with good results as optimization method facilitating decision-making in this field.

References

[1] Ballou Ronald H. Logística Administración de la Cadena de Suministro. Quinta Edición, México: Pearson educación, 2004 págs., 14 y 64.

[3] Bellman, R. & DreyFus, S. Applied Dynamic Programming. Princeton University Press, 1962.

[4] Winston, W.L Investigación de Operaciones. Aplicaciones y Algoritmos. Editorial Iberoamérica, 1994.

[5] Obando Solano, J. P., Zamora Moreno, J. A., & Giraldo Ramos, F. N. (2016). Algoritmo de optimización de colonias de hormigas para el problema de distribución en planta.

[6] Yang, X. S. (2009, October). Firefly algorithms for multimodal optimization. In International symposium on stochastic algorithms (pp. 169-178). Springer, Berlin, Heidelberg.

[7] Yang, X. S. (2010). Nature-inspired metaheuristic algorithms. Luniver press.

[8] M.M. Flood, The traveling salesman problem, Operations Research, Vol. 4, No. 1, Feb. 1956.

[9] G. Dantzig, R. Fulkerson, S. Johnson, Solution of a Large-Scale Traveling-Salesman Problem Journal of the Operations Research Society of America, Vol. 2, No. 4 (Nov., 1954), págs. 393-410

[10] M. Nourelfath, N. Nahas, and B. Montreuil, “Coupling ant colony optimization and the extended great deluge algorithm for the discrete facility layout problem,” Engineering Optimization, vol. 39(8), 2007, pp. 953-968

[11] Saraei, M., Analouei, R., & Mansouri, P. (2015). Solving of travelling salesman problem using firefly algorithm with greedy approach. Fen Bilimleri Dergisi (CFD), 36(6).

[12] Yang, X. S., & He, X. (2013). Firefly algorithm: recent advances and applications. International journal of swarm intelligence, 1(1), 36-50.

[13] Łukasik, S., & Żak, S. (2009, October). Firefly algorithm for continuous constrained optimization tasks. In International conference on computational collective intelligence (pp. 97-106). Springer, Berlin, Heidelberg.

[14] Yang, X. S. (2013). Multiobjective firefly algorithm for continuous optimization. Engineering with computers, 29(2), 175-184.

[15 Jati, G. K. (2011, September). Evolutionary discrete firefly algorithm for travelling salesman problem. In International conference on adaptive and intelligent systems (pp. 393-403). Springer, Berlin, Heidelberg.

[16] Fister, I., Fister Jr, I., Yang, X. S., & Brest, J. (2013). A comprehensive review of firefly algorithms. Swarm and Evolutionary Computation, 13, 34-46.

[17] Fister Jr, I., Yang, X. S., Fister, I., & Brest, J. (2012). Memetic firefly algorithm for combinatorial optimization. arXiv preprint arXiv:1204.5165.

[18] Contreras, R.: Modelo de optimización en la generación de plantas industriales, considerando las actividades de mantenimiento y las condiciones ambientales mediante el uso de la metodología de los algoritmos genéticos. Tesis para optar el título de doctor. Universidad Politécnica de Valencia, 81-281, (2010).

[19] J. Gonzalez, I. Rojas, H. Pomares, M. Salmeron and J.J. Merelo (2002). “Web newspaper layout optimization using simulated annealing.” IEEE Transactions on System, Man, and Cybernetics, Part B 32(5), pp. 686-691.

[20] Martí R.: Procedimientos metaheurísticos en optimización combinatoria. Universidad de Valencia. Departament d’Estadística i Investigació Operativa. Facultat de Matemátiques, 2-9, (2003).