**Int. J. Res. Ind. Eng. Vol. 9, No. 2 (2020) 172–182**

IJRIE

**International Journal of Research in Industrial Engineering**

**www.riejournal.com**


# Finding Optimum Facility's Layout by Developed Simulated Annealing Algorithm

H. Jafari [1,*], M. Ehsanifar[2], A. Sheykhan[2]

[1]Young Researchers and Elite Club, Arak Branch, Islamic Azad University, Arak, Iran.
[2]Department of Industrial Engineering, Islamic Azad University of Arak, Arak, Iran.

**A B S T R A C T**

**T**he Quadratic Assignment Problem (QAP) is one of the problems of combinatorial optimization belonging to the NP-hard problems' class and has a wide application in the placement of facilities. Thus far, many efforts have been made to solve this problem and countless algorithms have been developed to achieve the optimal solutions; one of which is the Simulated Annealing (SA) algorithm. This paper aims at finding a suitable layout for the facilities of an industrial workshop by using a Developed Simulated Annealing (DSA) method.

**Keywords:** Simulated Annealing, Meta-heuristic, Facility Layout Problem (FLP), DSA method.

***Article history:*** *Received: 03 December 2019* *Revised: 12 April 2020* *Accepted: 05 May 2020*

## 1. Introduction

The facility layout or the Quadratic Assignment Problem (QAP) is a spatial layout of goods production or service provision facilities. Koopmans and Beckmann were the first to define the issue of layout of facilities as a common industrial problem [1].

The design of the layout is an optimization problem that tries to make deployment more efficient and taking into account the various interactions between the facilities and materials transportation system [2]. The layout problem is used in many production systems. Typically, the problem of placing facilities (including offices and machinery) is in the factory space. Since the layout is affecting transportation costs, usually the main cost in manufacturing organizations, efficient layout will have a significant role in the performance of the organization. Transportation costs account for 20 to 50 percent of the total operating costs and also 15 to 70 percent of the cost of producing a commodity. This cost is calculated based on the flow of materials among the

* Corresponding author
E-mail address: hossein_jafari_123@yahoo.com
DOI: 10.22105/riej.2020.218913.1119

departments and the distance between them, and the best option is the arrangement that would have the lowest transportation cost [3].

For more than five decades, scientists have studied the QAP and have made remarkable discoveries in this regard. Most mathematical scientists, computer science experts, operative research analysts, and economists use the QAP to model a variety of optimization problems [4].

Mak et al. [5] in a paper used Genetic Algorithm (GA) as a general method to solve layout design problems. They developed a mathematical model to study layout of the devices and material flow pattern for workshop and product manufacturing environment. The suggested GA with the aim of minimizing material displacement cost extracts an optimum machinery layout [5]. Stützle [6] offered a new method called Iterated Local Search (ILS) to solve QAP. ILS is a simple random search method. First, some random points are created in search space, then based on the competence of the mentioned points, searching around them is started. One of the biggest challenge in Stützle's method is the radius in local search.

Hicks [7] in a paper developed GA to be used in facility layout in a set of productive cells. The results showed that the approach of redesigning facilities determines intracellular layout, then it localizes the cells among empty departments [7]. Azadeh and Izadbakhsh [8] in 2008 proposed an article on plant layout. The paper presents an integrated multivariate and multi attribute analysis approach for solving plant layout design problems. The integrated approach discussed in this paper is based on Principal Component Analysis (PCA) and Analytic Hierarchy Process (AHP). The validity of the model is verified and validated by Numerical Taxonomy (NT) approach.

Gao et al. [9] used a GA combined with a fuzzy clustering algorithm to locate a medical service center. In this research, objective function was minimizing the distance between the medical center and where the disaster had occurred. The GA was employed to find optimal locations so that the medical service center be located near the disaster place and be accessible in a short time. Golestaneh et al. [10] solved the Resource-Constrained Project-Scheduling Problem (RCPSP) using the GA, Tabu Search (TS), and Simulated Annealing (SA) algorithms. According to their results, the SA outperformed the GA and TA on average.

Pichka et al. [11] solved the Vehicle Routing Problem (VRP) and suggested the use of the SA to find the optimal routes between the customers and warehouses. Moradi and Shadrokh [12] investigated the Site Layout Planning (SLP) with equal and unequal surface areas. The SA algorithm was used to find the optimal layout. Comparison of the SA results with those of other algorithms showed the superiority of the SA in finding optimal solutions with high speed in a shorter time.

## 2. Problem Statement

Assignment implies that each facility conforms to one location and vice versa. In QAP, the number of facilities and locations should be equal. The mathematical format of this problem is as follows [13]:

$$\text{Min } Z = \sum_{i,j,k,s=1}^{n} D_{i,k} W_{j,s} x_{k,s}^{i,j}. \tag{1}$$

St:

$$\sum_{i=1}^{n} x_{i,j} = 1\ ;\ j = 1,2,\dots,n, \tag{2}$$

$$\sum_{j=1}^{n} x_{i,j} = 1\ ;\ i = 1,2,\dots,n. \tag{3}$$

$$x_{k,s}^{i,j} = x_{i,j} x_{k,s}. \tag{4}$$

$$x_{i,j} = \begin{cases} 0 \\ 1 \end{cases} ;\ i,j \in \{1,2,\dots,n\}. \tag{5}$$

The QAP is an exponential complex problem, as issues with dimensions larger than twenty ($n \geq 20$) can not be solved or a great amount of time is needed to solve them [14]. Hence, a meta-heuristic will be used to solve the layout problem in this article. The results of meta-heuristic algorithms, especially the SA algorithm, are highly dependent on the primary population or the first generation [15].

In other words, if an appropriate original solution is not available to the SA algorithm, the likelihood of finding better solutions (better layouts) is reduced. On the other hand, according to the rules of the SA algorithm, the primary solution must be created completely randomly and no precise operator has been introduced for creating the first solution so far. Therefore, in this research, which is dedicated to a case study, a simple method is suggested to solve this problem.

First, in the SA algorithm, there is no specific mechanism for selecting an initial guess for the solution. Second, if a proper initial solution is not selected, at the end of the algorithm, a proper solution may not be found. Thus, we run the SA algorithm several times and select a random initial solution for each run. This initially enables us to arrive at different solutions at the end of the algorithm, and then, to select the best solution (the lowest cost solution) among the identified solutions. Finally, we can compare the cost of the best solution with the cost of other solutions. In other words, one final solution presented by the SA algorithm may be different from another final solution presented by the very algorithm, among which we select the best solution. Hence, the proposed solution can enable the self-evaluation of the SA algorithm.

## 3. Proposed Methodology

SA algorithm is a simple and effective meta heuristic optimization algorithm for solving optimization issues in large search spaces. This algorithm is most often used in discrete search spaces. For problems where finding an approximate solution for global optimization is more important than finding a precise solution for local optimization in a fixed amount of time, SA algorithm may be preferable to alternatives such as gradient method [16].

The gradual cooling method is used by metallurgists to achieve a state in which solids are well arranged and energy is minimized. The purpose is maximizing the size of crystals in the solid state of the substance being annealed. This technique involves exposing the substance to high temperature and then gradually reducing the temperature. Simulated annealing is an approach that reduces the minimization issue of a multi-variable function to a statistical mechanics issue. The founders of this algorithm proposed a method based on gradual and slow cooling technique for solving difficult optimization issues. These investigators used computer simulation to simulate a system's annealing to find global minimum response [17].

To solve an optimization issue, the SA algorithm initially starts with a primary solution and then moves to neighboring solutions in an iteration loop. If the neighboring solution is better than the current one, the algorithm chooses it as the current solution (moves to it), otherwise, the algorithm accepts that solution as the current solution by the probability $\exp\left(-\frac{\Delta E}{T}\right)$. In this equation, $\Delta E$ is the difference between the target function of the current solution and the neighboring solution, and T is a temperature parameter. At each temperature, several iterations are performed, and then the temperature is slowly reduced. In the initial steps, temperature is set very high so that it is more likely to accept worse solutions. As temperature gradually decreases, it is less likely to accept worse solutions in the final steps, thus the algorithm converges to the best solution. SA algorithm is an unbound algorithm used for complicated designs [18]. Various steps of SA algorithm are shown based on the preceding statement in ***Figure 1***.

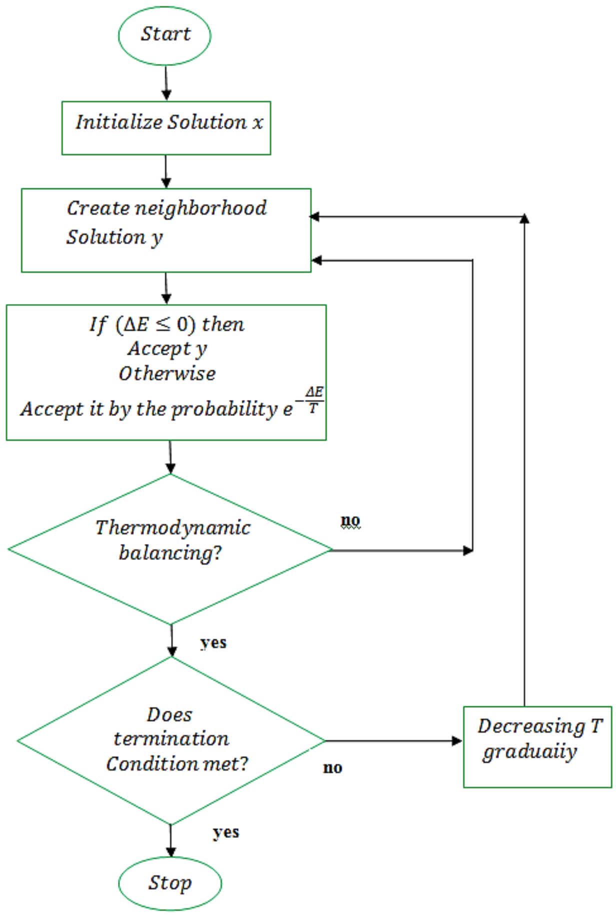


***Figure 1.*** Simulated Annealing flowchart [16].

After completing the computer codes associated with the SA, the algorithm is placed in a repeating loop and it will be executed countless times (N). This causes the algorithm to be very diverse in the first generation. Finally, the best scenario is chosen from the recovery scenarios. Depending on the importance of the problem, researchers can select the N number large or small. Obviously, choosing larger Ns will yield more reliable results. Various steps of Developed Simulated Annealing (DSA) algorithm are shown based on the preceding statement in ***Figure 2***.

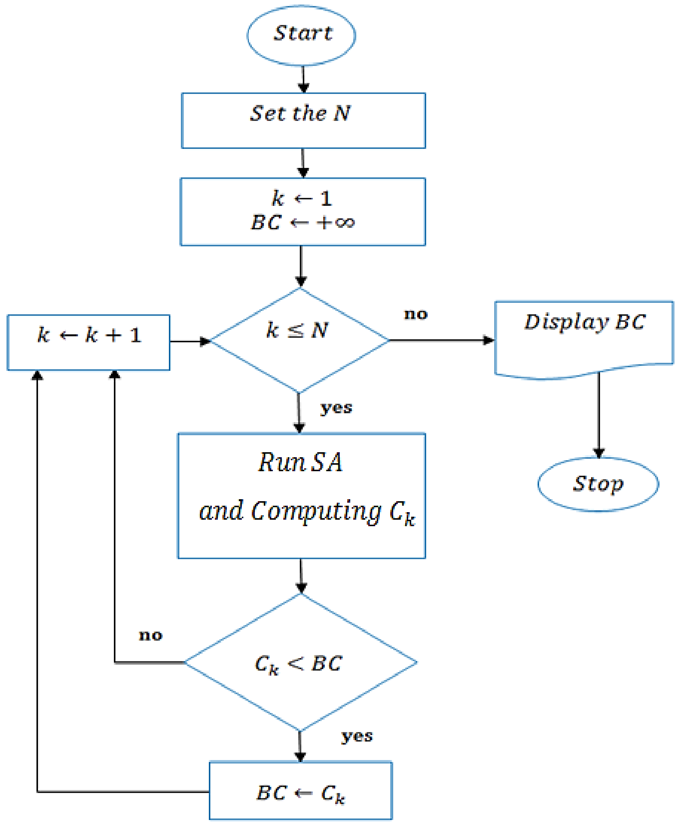


***Figure 2.*** Developed simulated Annealing flowchart**.**

**Note.** In ***Figure 2***, the value of $C_k$ is the lowest value found in the kth implementation of the SA algorithm. Also, the BC variable means the best cost found in the DSA algorithm.

## 4. Case Study and Results

A case study in this research involves an industrial workshop producing a variety of wood and metal products. The workshop consists of 20 of facilities and 20 of stations. The purpose of this paper is to establish optimal facilities at stations, based on the distance between stations and the machines transportation flow. The distance between the stations is shown in ***Table 1***.

***Table 1.*** Station distance matrix.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **1** | | | | | | | | | | | | | | | | | | | |
| **2** | 9 | **2** | | | | | | | | | | | | | | | | | | |
| **3** | 17 | 9 | **3** | | | | | | | | | | | | | | | | | |
| **4** | 25 | 17 | 8 | **4** | | | | | | | | | | | | | | | | |
| **5** | 33 | 25 | 16 | 8 | **5** | | | | | | | | | | | | | | | |
| **6** | 42 | 33 | 25 | 17 | 9 | **6** | | | | | | | | | | | | | | |
| **7** | 50 | 41 | 33 | 25 | 17 | 8 | **7** | | | | | | | | | | | | | |
| **8** | 58 | 50 | 41 | 33 | 25 | 17 | 9 | **8** | | | | | | | | | | | | |
| **9** | 66 | 58 | 49 | 41 | 33 | 25 | 17 | 8 | **9** | | | | | | | | | | | |
| **10** | 74 | 66 | 57 | 49 | 41 | 33 | 25 | 16 | 8 | **10** | | | | | | | | | | |
| **11** | 82 | 74 | 65 | 57 | 49 | 41 | 33 | 24 | 16 | 8 | **11** | | | | | | | | | |
| **12** | 8 | 12 | 19 | 26 | 34 | 42 | 50 | 59 | 66 | 74 | 82 | **12** | | | | | | | | |
| **13** | 12 | 8 | 12 | 18 | 26 | 34 | 42 | 50 | 58 | 66 | 74 | 9 | **13** | | | | | | | |
| **14** | 19 | 12 | 8 | 11 | 18 | 26 | 33 | 42 | 50 | 58 | 65 | 17 | 9 | **14** | | | | | | |
| **15** | 26 | 18 | 11 | 8 | 11 | 18 | 26 | 34 | 42 | 50 | 58 | 25 | 17 | 8 | **15** | | | | | |
| **16** | 34 | 26 | 18 | 11 | 8 | 12 | 18 | 26 | 34 | 42 | 50 | 33 | 25 | 16 | 8 | **16** | | | | |
| **17** | 42 | 34 | 26 | 18 | 12 | 8 | 11 | 18 | 26 | 33 | 41 | 42 | 33 | 25 | 17 | 9 | **17** | | | |
| **18** | 50 | 42 | 33 | 26 | 18 | 11 | 8 | 12 | 18 | 26 | 33 | 50 | 41 | 33 | 25 | 17 | 8 | **18** | | |
| **19** | 59 | 50 | 42 | 34 | 26 | 18 | 12 | 8 | 11 | 18 | 25 | 58 | 50 | 41 | 33 | 25 | 17 | 9 | **19** | |
| **20** | 66 | 58 | 50 | 42 | 34 | 26 | 18 | 11 | 8 | 11 | 18 | 66 | 58 | 49 | 41 | 33 | 25 | 17 | 8 | **20** |

The percentage of displacement between machines is shown in ***Table 2***.

***Table 2.*** Matrix of transportation percentage between facilities.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **1** | | | | | | | | | | | | | | | | | | | |
| **2** | 10 | **2** | | | | | | | | | | | | | | | | | | |
| **3** | 0 | 10 | **3** | | | | | | | | | | | | | | | | | |
| **4** | 0 | 11 | 0 | **4** | | | | | | | | | | | | | | | | |
| **5** | 0 | 0 | 0 | 0 | **5** | | | | | | | | | | | | | | | |
| **6** | 0 | 0 | 0 | 9 | 0 | **6** | | | | | | | | | | | | | | |
| **7** | 0 | 0 | 10 | 0 | 0 | 0 | **7** | | | | | | | | | | | | | |
| **8** | 11 | 0 | 0 | 0 | 0 | 9 | 0 | **8** | | | | | | | | | | | | |
| **9** | 14 | 18 | 11 | 0 | 0 | 0 | 0 | 12 | **9** | | | | | | | | | | | |
| **10** | 0 | 0 | 0 | 0 | 10 | 9 | 9 | 13 | 0 | **10** | | | | | | | | | | |
| **11** | 0 | 10 | 9 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | **11** | | | | | | | | | |
| **12** | 12 | 13 | 17 | 11 | 0 | 0 | 7 | 12 | 0 | 0 | 0 | **12** | | | | | | | | |
| **13** | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | **13** | | | | | | | |
| **14** | 10 | 14 | 9 | 12 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **14** | | | | | | |
| **15** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **15** | | | | | |
| **16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **16** | | | | |
| **17** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **17** | | | |
| **18** | 12 | 9 | 10 | 9 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **18** | | |
| **19** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | **19** | |
| **20** | 11 | 12 | 0 | 0 | 0 | 0 | 0 | 10 | 21 | 0 | 11 | 0 | 0 | 12 | 0 | 0 | 9 | 0 | 0 | **20** |

To determine the best-case layout, the proposed algorithm has been used with N= 150. In ***Figure 3***, the amount of best costs is presented in various algorithm performances.

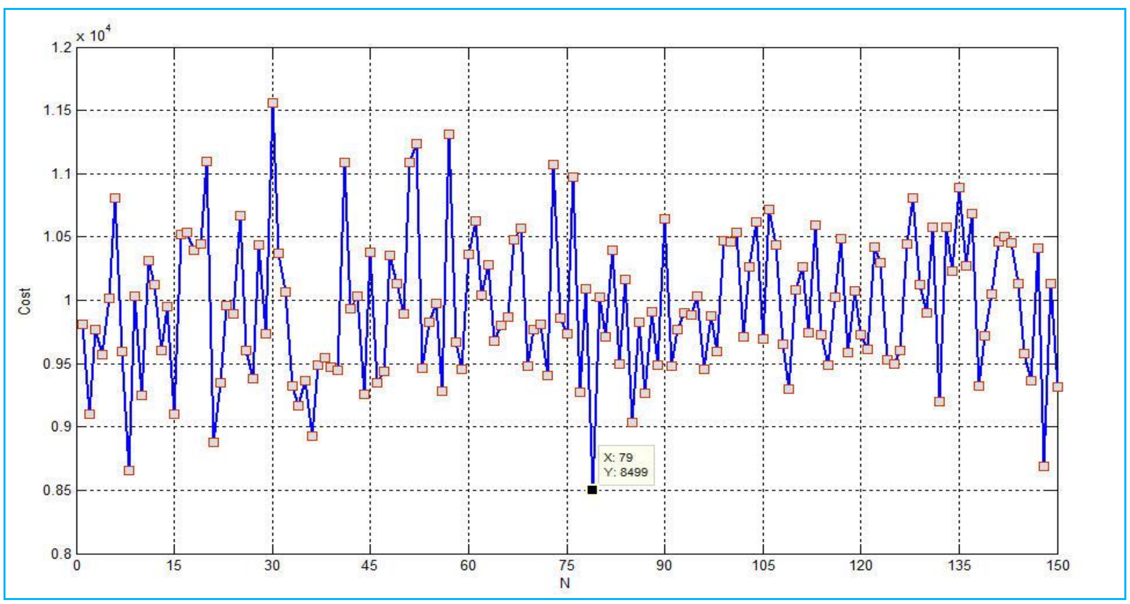


***Figure 3.*** The amount of best costs in various algorithm performances.

The results show that the layout obtained from the proposed method to find the best layout costs 8499. The optimal layout is also shown in ***Table 3***.

**Table 3.** Optimal layout by DSA method (Permutation).

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Facility | 11 | 20 | 8 | 1 | 12 | 7 | 18 | 5 | 6 | 13 |
| Location | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Facility | 15 | 17 | 9 | 2 | 14 | 3 | 4 | 10 | 16 | 19 |

According to both tables, it can be concluded that if the fifth machine is located at station eight and the remaining machines are arranged according to the data of the two preceding tables, the studied industrial unit can reduce transportation costs and move towards improvement.

## 5. Discussion

In this research, we used a case study to evaluate the performance of the SA algorithm. Given that we had no precise mechanism for selecting the initial solution, we tried to solve this issue using random solutions. Yet, the next challenge was to determine which initial solution had better results. To solve this challenge, we looked at the final cost of each solution. The best solution (arrangement) was definitely the one with the lowest cost. This solution's cost was 8499. The lowest cost arrangement was better than the many solutions.

One of the most important parameters in the SA algorithm is the initial temperature (T). The value of this parameter is set at 100 in MATLAB by default. We manually changed it and did not observe much improvement in the results and thus we set it back to 100 again. It is worth noting that the termination condition at each run was the number of iterations. In other words, the SA algorithm's termination condition at each run was set at 5000 iterations. After running the new algorithm in MATLAB, it was found that the running time of the new algorithm was 4.6668 minutes. There was not any constraint regarding the value of N, so we set it at 150. It is worth noting that the reliability of the solutions is greater at higher N. It is obvious that the running time of the algorithm increases at higher N, therefore, we set N at 150.

The value of the objective function for the current facility layout of the workshop under investigation is 9032. However, the objective function for the proposed layout by the DSA algorithm is 8499. As a result, it seems that the proposed algorithm can reduce costs significantly.

***Figure 3*** shows the solution developed by the base SA algorithm and the role of this new algorithm is to select the best solution among the available solutions. In conclusion, the new algorithm outperforms the based algorithm in finding the solution.

## 6. Conclusion

Proper layout of facilities has a direct relationship with the final cost of goods in large and small manufacturing units. If an incorrect location is found for facilities in industrial units, it is evident that the more interactions between workstations or departments of production unit increase, the more manufacturing costs will increase. Meanwhile, the mentioned problem is one of the exponential complex problems that generally needs meta-analysis methods to be solved. In this study, by adding a simple step with SA, attempts were made to create generations with greater diversity so that the algorithm DSA could achieve better results and it does not stuck in local extreme. The optimization researchers are recommended to repeat these algorithms in large numbers to increase the reliability of the extracted solutions from the meta-heuristic algorithms and finally select the best solution from the identified ones.

## 7. Acknowledgment

Hereby, the Sajjad Cabinet Manufacturing Company is thanked for providing us with the required data.

## References

[1] Koopmans, T. C., & Beckmann, M. (1957). Assignment problems and the location of economic activities. *Econometrica: journal of the econometric society*, 53-76.

[2] Azadivir, F., & Wang, J. (2000). Dynamic facility layout design using simulation and genetic algorithms. *International journal of production research*, 38, 4369–4383.

[3] Gupta, T., & Seifoddini, H. I. (1990). Production data based similarity coefficient for machine-component grouping decisions in the design of a cellular manufacturing system. *The international journal of production research*, *28*(7), 1247-1269.

[4] Afentakis, P., Millen, R. A., & Solomon, M. M. (1990). Integrated approach to facilities layout using expert systems. *International journal of production research*, *28*(2), 311-323.

[5] Mak, K. L., Wong, Y. S., & Chan, F. T. S. (1998). A genetic algorithm for facility layout problems. *Computer integrated manufacturing systems*, *11*(1-2), 113-127.

[6] Stützle, T. (2006). Iterated local search for the quadratic assignment problem. *European journal of operational research*, *174*(3), 1519-1539.

[7] Hicks, C. (2006). A Genetic Algorithm tool for optimising cellular or functional layouts in the capital goods industry. *International journal of production economics*, *104*(2), 598-614.

[8] Azadeh, A., & Izadbakhsh, H. R. (2008). A multi-variate/multi-attribute approach for plant layout design. *International journal of industrial engineering: theory, applications and practice*, *15*(2), 143-154.

[9] Gao, X., Zhou, Y., Amir, M. I. H., Rosyidah, F. A., & Lee, G. M. (2017). A hybrid genetic algorithm for multi-emergency medical service center location-allocation problem in disaster response. *International journal of industrial engineering: theory, applications and practice*, *6*(24), 32-41.

[10] Golestaneh, R., Jafari, A., Khalilzadeh, M., & Karimi, H. (2013). Minimizing total resource tardiness penalty costs in the resource constrained project scheduling problem with metaheuristic algorithms. *International journal of research in industrial engineering*, *2*(3), 47-57.

[11] Pichka, K., Ashjari, B., Ziaeifar, A., & Nickbeen, P. (2014). Open vehicle routing problem optimization under realistic assumptions. *International journal of research*, *3*(2), 46-55.

[12] Moradi, N., & Shadrokh, S. (2019). A simulated annealing optimization algorithm for equal and un-equal area construction site layout problem. *International journal of research in industrial engineering*, *8*(2), 89-104.

[13] Xia, Y. (2010). An efficient continuation method for quadratic assignment problems. *Computers & operations research*, *37*(6), 1027-1032.

[14] Gary, M. R., & Johnson, D. S. (1979). *Computers and intractability: a guide to the theory of np-completeness*.

[15] Schmitt, L. M., Nehaniv, C. L., & Fujii, R. H. (1998). Linear analysis of genetic algorithms. *Theoretical computer science*, *200*(1-2), 101-134.

[16] Černý, V. (1985). Thermodynamical approach to the traveling salesman problem: an efficient simulation algorithm. *Journal of optimization theory and applications*, *45*(1), 41-51.

[17] Kirkpatrick, S., Gelatt, C. D., & Vecchi, M. P. (1983). Optimization by simulated annealing. *Science*, *220*(4598), 671-680.

[18] Ohmori, S., Yoshimoto, K., & Ogawa, K. (2010, October). Solving facility layout problem-continuous simulated annealing. *2010 8th international conference on supply chain management and information* (pp. 1-5). IEEE.