Optimal Design of the Facility Layout using Improved Particle Swarm Optimization

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Abstract
Due to the increased competition in manufacturing industries play a driving force towards reducing the manufacturing costs by efficient design of facility layout. The success of manufacturing industries depends on the design of the facility that is able to adapt quickly and effectively for any changes in market requirements, technological changes, etc. The Facility Layout Problem (FLP) is a common industrial problem of allocating facilities to either maximize adjacency requirement or minimize the cost of transporting materials between them. The objective of the minimization of transportation cost from one department to other is calculated by multiplying together the flow distance with unit transportation cost per distance for each facility pair. Several researchers have used different methodologies for getting the better solutions of facility layout problems. This research proposed a methodology for getting the optimal design of the facility layout problems using the optimization method like particle optimization technique and genetic algorithm. The improved Particle swarm optimization technique has used to design a plant layout for minimizing material handling cost under the constraints of aspect ratios, dimensions of facilities and passages. The optimum result has been generated using the Particle Swarm Optimization (PSO) algorithm written in programming language C. A comparative study has carried out with the existing algorithm and tested the performance of the proposed algorithm. In this study a generalized form of FLP is formulated to find the optimum layout configuration for different no of facilities, different areas of facility, different passage configuration etc.

Keywords
Plant Layout Problem, Particle Swarm Optimization, Minimum Material Handling Cost, Inner Structure Walls, Genetic Algorithm

I. Introduction

A Layout planning includes aarray of demands coming from the requirements of inventory, product, scheduling, communication, physical factory conditions in a manufacturing system. In modern manufacturing environments, facility or plant layout problems can be solved using Facility layout Planning (FLP), for planning the location of all machines, employee workstations, areas to serve customers, areas to keep materials, lunchrooms, internal walls, offices, and computer rooms and for the flow patterns of materials and people around, into, and within buildings. The FLP has cost inferences for the operation and maintenance of the work in progress, load balancing, material handling system, and many other objectives. Facility layout problems (FLPs) are focusing the optimization of space layout, which has been investigated in depth by many researchers in various areas like architecture, management science, industrial engineering. The FLP can be classified into two categories either an equal area layout problem or an unequal area layout problem. The equal area layout problem is to determine how to assign a set of distinct facilities, to a set of distinct locations, so that each facility can be assigned to a single locationcalled as one-to-one assignment problem. The unequal area layout problem is to regulatethe allocation of all facilities within a block plan (or available area). The unequal area layout problem is much more difficult than the equal area layout problem due to its complexity. In the unequal area layout problem a facility is represented as a polygon that should be able to take on any shape and location, while maintaining a required area of the facility. The unequal area layout problem further can be classified into two categories, a grid-based block plan layout problem or a continual block plan layout problem.

In the grid-based block plan layout problem, the facility layout is constructed on the grid plan, which is further divided into squares or rectangles having a unitarea. A continual plan has been applied to construct a continual block plan layout problem. A grid-based block plan layout problems with a single floor can be solved using various algorithms such as CORELP [1] and FRAT[2], which have been developed by several researchers. For single and multi-floor facility layout problems, can be solved by using an algorithm called MULTIPLE has been developedand presented [3] and extension of MULTIPLE to SABLE by employing a simulated annealing (SA) method described [4]. A bandwidth concept has been implemented to construct the facility layout with a genetic algorithm [5]. A major drawback of the algorithms mentioned above is that, they are unable to solve problems having an irregular shape in the final layout. To control the final shape of facilities in the grid-based block plan layout problem is very difficult as they are allocated along agrid. To solve this drawback, a method has proposed to modify facilities irregular shapes into rectangular shapes, without significant changes in the relative positions of the facilities described [6]. Recent researchers have focused on development of algorithms for the continual block plan layout problem, where plan is not divided into unit areas by a grid. Ahierarchical procedure for the FLPs, has presented with a shape constraint, such as an aspect ratiopresented [7]. An evolutionary technique, like simulated annealing and genetic algorithmhas been proposed for solving a continual block plan layout problem to a Slicing Tree Structure (STS) that contains information about partitioning the plan presented [8-9]. A bay structure has proposed to construct the facility layout and solved the continual block plan layout problem using genetic algorithm has presented [10]. Graph theoretic algorithms have also been used for solving the unequal area layout problem. A graph theoretic algorithm has presented called SPIRAL, in which the facility layout is constructed through a maximum weighted planar graph[11]. This graph contains information about relative positions of the facilities. The use of graph theoretic heuristics in the facility layout problems has been presented [12]. In these heuristics, an initial layout is obtained by constructing a planar adjacency graph, which further can be improved by changing the adjacency graph. However, the above mentioned algorithms cannot be considered for the unequal area layout problem having inner structure walls and passages in the block plan. They are also limited to a rectangular boundary shape of the block plan. Therefore, these algorithms could not be directly applied to problems such as ship compartment layout.

Particle Swarm Optimization (PSO) is based on the flock movement of swarms, while searching for food as part of examining the conception of collective intelligence. Each member in PSO called as a particle and the population is called as swarm. The PSO algorithm has explained based on the concept of solution swarm as bird swarm, the movement of birds from one place to another is equal to the development of the solution swarm, same way good information while searching food transmitted by any bird to all is equal to optimist solution and finally food resource is equal to the most optimist solution during all iterations described [13]. The most optimist solution in PSO can be achieved by cooperation of each individual. In PSO, a randomly generated solution proliferates in the design space in the direction of the optimal solution by number of iterations using informations about the design space. PSO algorithms comprise of three steps, first to generate particle's positions and velocities, then update velocities, and finally update particles position. Here, a particle denotes to a point in the design space that changes its position from one move (iteration) to another based on velocity updates. Inthisstudy,animproved genetic algorithm (GA) is proposed for solving the unequal area layout problem having the inner structure walls and passages within an available area of a curved boundary. The performance of the proposed algorithmis better than other algorithm for the optimal facility layoutdesign.Finally,theproposed algorithm has applied to a shipcompartment layout problem having inner structure walls and passages then computational results have been compared with an actual ship's compartment layout. This research focused on following considerations:

1. The layout is Process Layout.
2. There are passage and inner structural wall in the layout so distance calculation between departments is not possible by using rectilinear method. This research has considered an ew method of distance calculation using nodal method.
3. The boundary shape of layout as rectangular, however it can be applied to any irregular shape of area also.
4. The only criteria of optimization have been taken as minimum material handling cost and adjacency ratio.
5. The paper has considered Particle Swarm Optimization (PSO) for the optimization technique of layout.
6. The maximum no. of department is 20. However, it can be used for more no.of department.

The rest of the paper has been arranged like in section II, a brief literature review of the experiment has been stated. Model Formations has been presented in section III. Results and Discussion for this research is described in section IV. Finally, section V presents conclusions.

II. A Brief Literature Review

Mihajlovic et al. [14] have applied the artificial Genetic algorithm to achieve the optimal machine layout for reducing the cost of the total material handling. The proposed mythology has been tested on differnet problems and found better results compared to many existing algorithms in this areapresented [14]. An ordered weighted averaging operator has been used to improve GA and introduce a new evolutionary technique, namely a Psycholonal Algorithm to analyze and solve facility layout optimization problem[15]. The application of Genetic Algorithm methodology in facility layout problem to gauge current and developing trends towards multi-objective approaches to layout and material handling system design presented [16]. An artificial neural network technology has been applied to the design the lean facility layout system to a cylinder production line to improve utilization ration of equipment's, reduce waste and improve production efficiency [17]. A particle swarm optimization meta-heuristic model has been suggested to establish emergency supplies distribution and decision model by Qi et al. [18]. An efficient hybrid meta-heuristic has been suggested based on variable neighborhood search and simulated annealing to design an optimal layout within defined planning horizon by Hasani et al. [19]. In this research, Genetic Algorithm explained [20] has been applied to develop the fixed and variable width column codification model to resolve layout problems and parametric representation has beendemonstrated [21]used for the formulation of the problem.

A. Problem Formulation

Facility layout can be represented as a chromosome using an encoding process. In this paper, a method to model the facility layout in a four-segmented chromosome, including positions of passages, has been proposed and shown in fig. 1. The 1st segment of the chromosome represents a sequence of facilities to be allocated. The 2nd segment represents areas of the facilities, that has given in the same order as the 1st segment and are allowed to vary between their upper and lower bounds. The 3rd and 4th segments respectively represent positions of the horizontal and vertical passages in terms of distances from the origin O as shown in fig. 1. The positions of the passages are allowed to vary between their upper and lower bounds.

For columns with a fixed width codification consists of assigning a number to each department, so that each individual (layout) in the population will be made up of a string of numbers, each of which represents a department. The position of the department in the facility has been shown by the position in the string, for illustration (2, 3, 1) designates that there are three departments on that particular floor of the facility, and they are in the following order: 1st department 2, follows by department 3, and finally department 1 as the physical representation of this individual. Fig. 1 shows, how departments can have unusual, irregular shapes, as a consequence of dealing with fixed width columns. In this particular example, this can be seen in department 3. Fig. 1 shows an example of the facilities layout together with the corresponding representation of the four-segmented chromosome.

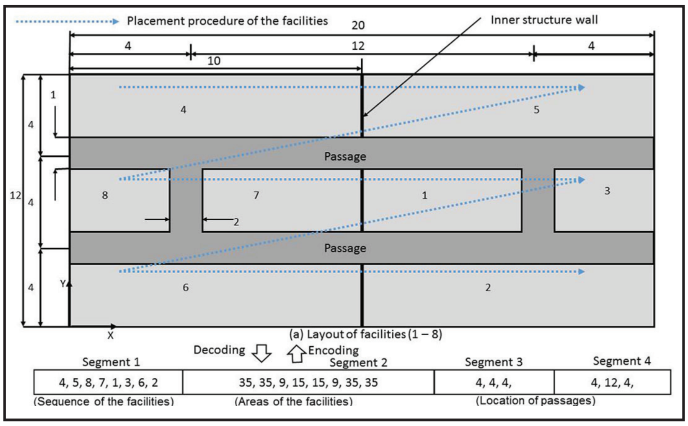

Fig. 1: Representation of a Four Segmented Chromosomes

For variable width columns all the departments will have a regular, rectangular shape, and the possibility of a department having a 'strange' shape is thereby eliminated. Each column will be of the width required for departments assigned to it to fit within the dimensions of its surface. Duringcodification, each individual consists of two sub-strings. The first sub-string is same as that for the fixed-width columns. Whereas, the second sub- string of the same size of the first sub-string, will contain additional information, required to identify when to move from one column to the next. This auxiliary information has made of ‘0’ and ‘1’. A ‘0’ represents that the column has not been completed, and a ‘1’ represents that the department is the last one in a row, and that the column is thereby complete. Double string is used for representing variable width column has been shown in Table 1.

Table 1: Double String Codification

4, 5, 8, 7, 1, 3, 6, 2
0, 1, 0, 0, 0, 1, 0, 1

Table 1 indicates that facility number 4 and 5 are in first column, facility number 8, 7, 1, and 3 are in second column, and facility number 6 and 2 are in third column placed.Fig. 1 shows the arrangement offacilities in the available rectangular area with the inner structure walls and passages. Most of the earlier facility layout problems had not considered the passages and inner structure walls, where as in accurate condition there will be passages and inner structure walls presented within the facilities, where in the material flow between the facilities takes place.The maximum allowable dimensions of each of the facilities within the given available rectangular area and its passages are given below:

Table 2: Parametric Representation of Plant Layout Problem

Sequence of facilities	**Areas of the facilities**	**Aspect ratios of the facilities**
4, 5, 8, 7	35, 35, 9, 15	0.8, 0.6, 1.1, 1.2
1, 3, 6, 2	15, 9, 35, 35	1.4, 0.5, 0.4, 0.7

B. Optimization Technique

Particle Swarm Optimization (PSO) is a population based stochastic optimization technique developed [22], inspired by social behavior of bird flockingor fish schooling. PSO is a swarm intelligence method that roughly models the social behavior of swarms [23]. PSO method is an evolutionary computational technique having a feature of both Genetic Algorithms (GA) and evolutionary strategies (ES) demonstrated [24]. It is similar to GA in that the system is initialized with a population of random solutions and searches for optima by updating generations. However, evolution operators such as crossover and mutation are not present in PSO, which plays important role in GA. In PSO, particles are the potential solutions,which fly through the problem space by following the current optimum particles. In compared to GA, it is easy to implement PSO as there are few parameters to adjust in it. PSO has been effectively applied in many areas: artificial neural network training, fuzzy system control, function optimization, and other areas where GA can be applied. The PSO algorithm simulates the behaviors of bird flocking. For example, a group of birds are randomly searching food in an area, where only one piece of food is present. As birds do not know the exact location of the food, but they know how far is it in each iteration. So what’s the best strategy to find the food? The effective way is follow the bird, which is adjacent to the food. PSO learned from the scenario and used it to solve the optimization problems. In PSO, each single solution is a “bird” in the search space known as “particle”. All of particles have fitness values, which are evaluated by the fitness function can be optimized, and have velocities, which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles. Fig. 2 shows the PSO flow chart for the facility layout problem.

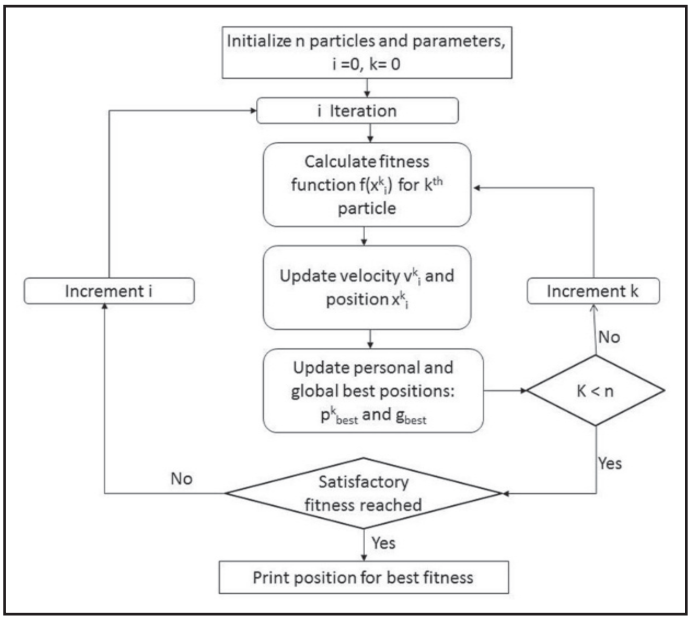

Fig. 2: Scheme of PSO Flow Chart for Facility Layout Problem

This research makes an attempt to utilize the advantages of the PSO algorithm and the result has been compared with the existing genetic algorithm. PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In each iteration, each particle is updated by following two “best” values. The first one is called pbest, is the best solution (fitness) achieved so far (the fitness value is also stored).Another “best” value is a global best value called gbestthat is followedby the particle swarm optimizer, which obtained so far by any particle in the population.When a particle takes part of the population as its topological neighbors, the best value is a local best and is called lbest. After finding the two best values, the particle updates its velocity and positions with following equations (a) and (b).

$$v[\,] = v[\,] + c1 * rand[\,] * (pbest[\,] - present[\,]) + c2 * rand * (gbest[\,] - present[\,]) \quad \ldots(a)$$

$$present[\,] = present[\,] + v[\,] \ldots(b)$$

v[] is the particle velocity, present [] is the current particle (solution), pbest[] and gbest[] are defined first best and global best, where as, rand() isa random number between (0,1). c1, c2 are learning factors. Usually c1 =c2 = 2. The pseudo code of the procedure is given as:

For each particle
- Initialize particle
- END
- Do
- For each particle
- Calculate fitness value.
- If the fitness value is better than the best fitness value (pBest) in history.
- Set current value as the new pBest
- End.
- Choose the particle with the best fitness value of all the

particles as the gbestfor each particle
- Calculate particle velocity according equation (a)
- Update particle position according equation (b)
- End while maximum iterations or a minimum error criterion is not attained.

Particles' velocities on each dimension are clamped to a maximum velocity Vmax. Whenever, sum of the accelerations would cause the velocity to exceed Vmax on that dimension. Then the velocity on that dimension is limited to Vmax.

III. Model Formations

FollowingsaretheInputDataforthemodel:
- Numbers of facilities have been allocated to the available area.
- Available area and its boundary shape.
- Area for each facility.
- Number of rows.
- No. of facilities in each row
- Material flows (load/or quantity) between facilities.
- Number and positions of inner structure walls.
- Number and widths of each vertical and horizontal passage.
- Position of each vertical and horizontal passage.

Table 3 shows the material flow between facilities. In this paper, the problem data has been taken from the research paper presented [21], using particle swarm optimization.

Table 3: Material Flow Matrix Between Facilities

Facility	1	2	3	4	5	6	7	8
1	0	15	0	0	0	5	5	10
2	15	0	25	40	100	90	80	70
3	0	25	0	0	0	20	30	200
4	0	40	0	0	30	10	0	0
5	0	100	0	30	0	50	70	20
6	5	90	20	10	50	0	5	0
7	5	80	30	0	70	5	0	10
8	10	70	200	0	200	0	10	0

A. Mathematical Model

The objective of this research is to minimize materials flow between facilities while at the same time satisfying the constraints of areas, aspect ratios of the facilities, and inner structure walls and passages. For getting the best facility layout, first determine the sequence and areas of the facilities to be allocated, and then the location of passages.

$$Minimize\ F = \sum_{i=1}^{M}\sum_{j=1}^{M} f_{ij} * d_{ij} \quad (1)$$

Subject to

$$g_1 = \propto_i^{min} - \propto_i \le 0 \quad (2)$$
$$g_2 = \propto_i - \propto_i^{max} \le 0 \quad (3)$$
$$g_3 = a_i^{min} - a_i \le 0 \quad (4)$$
$$g_4 = \sum_{i=1}^{M} a_i - A_{available} \le 0 \quad (5)$$
$$g_5 = \propto_i^{min} - \propto_i \le 0 \quad (6)$$
$$g_6 = (x_i^r - x_s^{i.s.w})(x_s^{i.s.w} - x_i^l) \le 0 \quad (7)$$

f_{ij}: Material flow between the facility i and j,
d_{ij}: Distance between centroids of the facility i and j,
M: Number of the facilities,
α_i: Aspect ratio of the facility i,
α_i^{min} and α_i^{max} : Lower and upper bounds of the aspect ratio α_i
a_i : Assigned area of the facility i,
a_i^{min} and a_i^{max} : Lower and upper bounds of the assigned area a_i
$A_{available}$: Available area,
P: Number of the inner structure walls,

B. Inter Departmental Distance Calculation using Nodal Method

A solution to the facility layout problem having passages and inner structure walls using particle swarm optimization has been demonstrated [19]. The rectilinear distance method cannot be employed for our problem having passages and inner structure walls,hence a new method is employed for the distance calculation between the facilities via the passages. In this paper, measurement of distance between departments has been done by considering the movement of materials from one department to anotherdepartment and also people walk between locations to do useful work. In this research, some nodes have established for eachfacility as shown in Figure 3, i.e., N1, N2, N3… N12, which begin with respect to the length of each facility, i.e. from the left side as the origin.

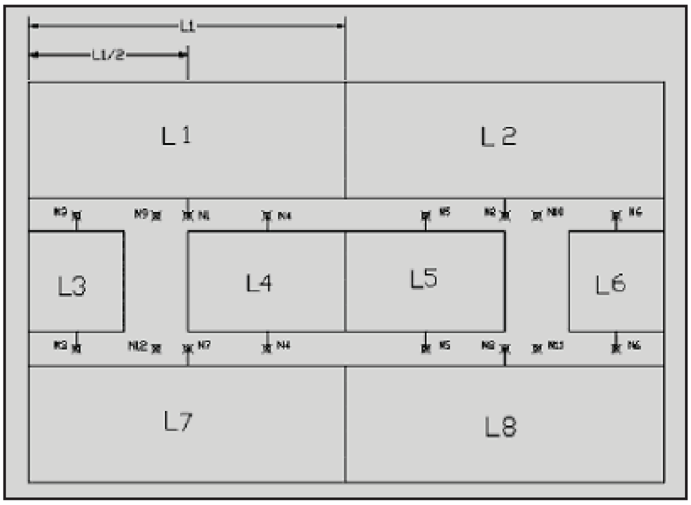

Fig. 3: Shows the Layout With Nodes for Distance Calculations

A1=35,w1=3.5,l1=35/3.5=10.N1=(l1/2) = 5. Similarly,N4 = l3 + 2 + (l4/2)andN6 = l3 + 2 + l4 + l5+ 2 +(l6/2).
Hence, distance between facilities 1 and 8 will be (N10−N1)+ 4 +(N11−N8)+c1+c8, where c1 and c8 represents the distance between the centroid of facilities 1 and 8 from N1 and N2 respectively.

IV. Results and Discussion

Problem Representation: One of the most important issue when designing the PSO algorithm lies on its solution representation. In order to construct a direct relationship between the problem domain and the PSO particles, we present n number of dimensions for n number of facilities. In other words, each dimension represents a typical job. In addition, the particle $X_{i1}^t = [x_{i1}^t, x_{i2}^t, x_{i3}^t, \ldots, x_{in}^t,]$. The paper has used SPV (shortest position value) rule to find out the best combination of layout sequence using particle swarm optimization. Problems with 8,10,15,20 facilities have been analyzed.

Table 4: Problem Representation using SPV Rule

S. No.	1	2	3	4	5	6	7	8
x_{ij}	-3.87	-3.95	0.02	-3.60	0.27	-1.39	2.44	-1.65
v_{ij}	-3.68	-3.88	0.99	-3.02	0.95	0.47	-1.19	0.23
Sequence	2	1	4	8	6	3	5	7

Initial Population: A population of particle is constructed randomly for PSO algorithm

- 16 bits of each 8 bit size dimension is taken
- Different positions are calculated by using formula

$$x_{i1} = x_{min} + (x_{max} - x_{min}) * U(0,1) \quad \text{(i)}$$

$$where, x_{min} = 0, x_{max} = 4, U(0,1) = random\ number\ between\ 0\ and\ 1$$

- Different velocities are calculated by using formula

$$x_{i1} = v_{min} + (v_{max} - v_{min}) * U(0,1) \quad \text{(ii)}$$

$$where, v_{min} = -4, v_{max} = 4, U(0,1) = random\ number\ between\ 0\ and\ 1$$

- Generating 16 initial solutions or population by sorting on the basis of smallest position value (SPV) rule, they the fitness value in each optimum solution is the pbest.

Table 5: 16 Initial Particle Population of 8-bit Size (Dimension)

S.No	Sequence of facility								Pbest
1	2	1	4	8	6	3	5	7	1260
2	8	5	3	4	7	6	1	2	1564.76
3	1	7	8	3	4	2	5	6	1435.24
4	5	8	6	7	4	2	3	1	1360
5	2	5	4	7	8	1	6	2	1245
6	8	5	4	2	6	1	7	3	1780
7	4	6	8	7	1	3	2	5	1675.73
8	5	4	7	8	1	2	3	6	1450.91
9	7	4	2	1	8	3	5	6	1015.47
10	1	2	8	7	3	5	6	4	9946.88
11	1	2	7	8	6	3	4	5	1031.86
12	1	7	2	6	3	4	5	8	1189.86
13	4	6	5	7	1	8	3	2	998.34
14	8	6	2	3	1	4	5	7	1150.64
15	2	7	8	4	5	6	3	1	1451.23
16	1	2	5	4	3	6	8	7	991.04

Thus finally the value of gbest = 991.04 has been achieved. After this, in each iteration, velocity and position have been updated using following equation:

$$v_{ij}^{t} = v_{ij}^{t-1} + c_1 \cdot (p_{ij}^{t-1} - x_{ij}^{t-1}) + c_2 \cdot (g_{ij}^{t-1} - x_{ij}^{t-1})$$

$$x_{ij}^{t} = x_{ij}^{t-1} + v_{ij}^{t}$$

$$where, p_{ij}^{t} = pbest\ in\ iteration\ "t"\ and\ g_{ij}^{t} = gbest\ in\ iteration\ "t"$$

After getting new position in second iteration, again used SPV (shortest position value rule) .The new gbest = 981.55.

After 40 iterations, it has been found that the data is continuously diverging so terminating from this iteration, finally, paper got the Ubest (universal best) =923.25.

Following results have been achieved:

- Final Testing of main program has been done for the given layout of size

1. 8 facilities
2. 10 facilities
3. 15 facilities
4. 20 facilities

- A Generalized and versatile form of the program is obtained for parameters like

1. Different area of layout.
2. Total number of facilitates to be allocated.
3. Number of rows.
4. Number of facilities in each row.
5. Area of each facility.
6. Dimension of each passage.

- After getting the result, paper has compared with some other heuristic method like Genetic algorithm.

PSO Algorithm

1. Generate random number
2. Generate 16 initial solutions by sorting on the basis of smallest position value (SPV) rule.
3. Finding distance, material handling cost for each initial solution in above program.
4. Combining all program and sorting on the basis of minimum material handling cost give the Pbest solution
5. Add velocity and then update velocity to find Gbest and Ubest.
6. Taking a number of iteration like 40, 60 or sometime 80 to get the optimum one.
7. Generalized form of program for all possible layout of given size.

The performance of an optimal facility layout design based on the genetic algorithm is well known presented [25]. In this study, author showed the competitive power of his algorithm by comparing it with other existing algorithms. Acomparative test of the proposed algorithm based on Kyu-Yeul Lee's algorithm has been used to evaluate the efficiency of the proposed algorithm [25]. For a more accurate comparison, being made equal to those of Kyu-Yeul Lee's algorithm modified the objective function, the chromosome structure, and the representation method of the facility layout of the proposed algorithm.Table 6 shows the comparison of computational results of proposed algorithm with standard result obtained by Kyu-Yeul Lee's genetic algorithm:

Table 6. Comparison of results of GA and PSO

No of facilities	Formal Genetic Algorithm		Proposed PSO Algorithm		Computa-tional Time ratio
	MHC	Computa-tional Time	MHC	Computa-tional Time	
8	27.225	1.9	25.125	1.5	1.27:1
10	28.012	2.5	27.225	2.1	1.19:1
15	31.175	3.2	30.102	2.9	1.11:1
20	37.198	4.0	37.002	3.7	1.39:1

The results obtained are summarized in Table 6 where the best among 10 objective function values, the mean of 10 objective function values, the mean of 10 computation times, and the ratio of the computation times have shown. From Table 6, it has been observed that the proposed algorithm is superior to Kyu-Yeul Lee's algorithm, as there are 0.526% better values of best and mean objective functions produced by the proposed algorithm and it required 30%less computation time. To evaluate the efficiency of the proposed algorithm, another comparative test of the proposed algorithm was performed. The testing was performed for eight facilities and the result obtained using the particle swarm optimization algorithm has shown in Table 7. Table 7 shows the comparison of computational result of proposed Algorithm with the algorithm proposed [19] using particle swarm optimization.

Table 7: Optimum Results

	Previous result	Our result
Optimum sequence	2-3-5-8-1-7-4-6	1-2-5-4-3-6-8-7
Objective value	981.75	923.25

V. Conclusion

In this paper, PSO as the proficient algorithm has been proposed for solving the facility layout problem having innerstructure walls and passages. This paper first formulated a mathematical model for the facility layout problem with inner structure walls and passages. The layout of facilities have modeled in a four-segmented chromosome, this included positions of passages. A Nodal methodhas proposedfor calculatingdistances between the facilities. The optimal layouts have obtained by getting the lower objective function. A comparison with an existing algorithm was performed to evaluate the proposed algorithm's efficiency. The comparison results show that the proposed algorithm is superior to the existing one.

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