An Approach of Designing Robust Plant Layout Using Genetic Algorithm

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Abstract
In today's competitive global environment, industries manufacture different types of products to fulfill market demands. This results into a number of diversified processes to be performed in industries. These processes are performed on different machines to produce a final product. So, a need arises for proper arrangement of machines in the workplace. For this, plant layout is an effective tool for allocating different machines to a different location. The main objective of plant layout is to provide smooth workflow throughout the facility. In this paper, a new model of the process type of plant layout is provided with an aim of minimizing the total material flow cost by reducing the unnecessary movement between the machines. The genetic algorithm is suggested to compute allocations of machines and estimation of cost incurred in the layout. Finally, a numerical illustration is discussed for reducing the material flow cost to prove the efficacy of the proposed model.

Keywords
Process layout; Plant layout problem; Genetic algorithm; Material handling cost

1. Introduction
The prime objective of any manufacturing industry is to maximize profit margins and at the same time, reduce costs. So, the function of production plays a key role in the success of the organization. For achieving efficient production and service systems, along with optimal planning and policies, there is a need of a well designed plant layout. Optimal Design of plant layout plays an important role not only in the initial stages, but also has a great influence at the later stage. It has a wide impact on productivity; work in process, manufacturing lead time, material handling cost and on other areas of operation Pillai et al. (2011). In general, the plant layout problem is concerned with reduction of material flow/handling cost. Since, material handling cost is one of the major costs incurred in production, which can contribute up to 20-50% of operating costs Chan et al. (2004). Material handling is a non-value adding activity. The efficiency of a plant can be increased by reducing such non-value activities.

Plant layout is a study which deals with the location and arrangement of different machines/facilities within a stipulated area in order to achieve greatest coordination and efficiency of 4M's (Men, Material, Machines and Methods) in a plant. Layout planning is a complex activity involving optimization of positions of machines and workstations. The objective of a good plant layout is to minimize material handling and movement of work from one department to the next.

There are different types of plant layout which are applicable in different industries according to their requirement. In this study, the problem is considered based on the process type of plant layout. The process layout can accommodate a variety of products. This requires a greater flexibility in production, thus allowing industries to fulfill a wide range of customer's demands. In this type of layout, machines are arranged according to the nature or type of operations performed for manufacturing purpose. Each product has a definite sequence of operations, not necessarily in the same order in which the machines are placed. So, there is frequently non-unidirectional movement of workflow takes place between the facilities, according to the changing demand of products. The objective of this study is to reduce the material handling cost by assigning the machine/facility in an optimal way in each location and hence, increase productivity.

Static plant layout (SPL) problem approach is suited for facility layout problems when the demand is more or less constant with time. But, when the demand is varied with respect to time, then, dynamic plant layout approach is more efficient for various planning horizons. There are two major approaches to solve dynamic plant layout problem. One approach is adaptive approach which assumes that the machines can be easily relocated from time to time with low rearrangement costs. On the other hand, the robust approach focuses on designing a layout with minimum the total material handling costs by assuming that the rearrangement cost as too high Pillai et al. (2011). Generally, in practice the rearrangement cost is very high in industries due to bulk movement of machines and complex rearrangement process. So, this study suggests a robust model for dynamic plant layout problem, by using genetic algorithm for layout formation. The remainder of this study is organized as follows. Section 2 discussed the concerned literature while problem formulation is provided in section 3. Numerical illustration along with the results is discussed in section 4. Finally, section 5 provides the concluding remark of this study.

2. Literature Review

With growing competition of products in the market, industrialist and researchers are trying to fulfill the customer demands by making it available at lower prices. One contributor to these prices is material handling costs. This cost can be reduced through proper design of plant layout. Previously, many researchers have contributed their efforts to develop methods for designing plant layout. Pillai et al. (2011) designed a robust facility layout by considering dynamic market demand. In their work, applied simulated annealing (SA) approach to a case study from the work of Chan et al. (2004) and obtained improved results for the same case study. They also used total penalty cost to test the suitability of robust layout for the case considered. There are various approaches to design the plant layout as well as to check its suitability to be a robust layout. Prasad et al. (2014) designed a manufacturing plant layout with a goal of minimizing the material flow cost by positioning the machines within the existing area. In their work, Standard for the Exchange of Product (STEP) file is considered as an input to Java program and output is obtained as a distance matrix between the locations. The distance matrix is used to calculate the layout cost. Computerized Relative Allocation of Facilities Technique (CRAFT) is then applied to design the plant layout. This results in significant reduction in layout cost.

Bock and Hoberg (2007) introduced a detailed layout planning by considering simultaneously both machine arrangements and transportation path. In their work, the analysis was performed by incorporating specific attributes to certain layout subareas and based on computational experiments; they developed a mathematical model which showed that the elaborate heuristics generate better layout configurations. Neghabi et al. (2014) focused on the effectiveness of a robust approach to solve facility layout problem (FLP). The authors have considered uncertainty in the size of the department length and for modeling this uncertainty; the department size is considered as a bounded variable and can be changed by using an agent based simulation model (ABSMODEL).

Shahin and Poormostafa (2011) proposed facility layout design improvement and optimization by using an integrated approach of simulation, quality function deployment and fuzzy analytic hierarchy process. Mishra et al. (2011) described the shifting cost of the machine and also use replacement analysis technique for redesigning the plant layout. The authors employed sampling technique for solving large size problem. Earlier researchers Balakrishnan et al. (2009), Balakrishnan et al. (2000), Corry et al. (2004), and Kulturel-Konak, S. (2007) had given flexible or adaptive or agile layout which can rearrange the facilities for the purpose of meeting the requirements of production.

A systematic layout planning theory for reducing the production cost is described by Hossain et al. (2015) where a detailed study of the operation process chart and activity relationship chart were investigated. Lee (2015) formulated a mathematical program for a multi floor plant layout problem. In this model, the author considered the safety distance as well as impacts of physical explosion on pipelines under different condition. The main objective is to minimize the pipeline cost for connecting equipments. The objective is achieved by employing a mixed integer nonlinear programming (MINLP) solvers. The results showed a more reasonable and safer plant layout.
Palomo-Romero et al. (2017) proposed island model genetic algorithm to solve unequal area facility layout problem and also maintained population diversity for obtaining wider sampling of the search space to get better quality solutions in fewer generations.

Use of Genetic algorithm (GA) as a tool for optimizing the parameters is also described by various researchers. Datta (2012) applied a proposed genetic algorithm to linear programming problems in finding the fittest chromosomes. Genetic algorithm is gaining more importance for solving different types of problems. Belea (2004) described and formulated the dynamic nature of genetic algorithm using the state equation by generalizing the schema theorem. The use of the generic genetic algorithm was made by Cuibus and Letia (2012), to test the system behavior and for the evaluation of control performances in a problem of lake system control.

Nicoara (2007) employed genetic algorithm for solving job shop scheduling problem in the pharmaceutical industry and described the problem as both single-objective and multi-objective problem by considering the various complexity. The results provided an efficient solution for the case study considered by the author. Halal and Dumitrache (2006) described the power of genetic algorithm for navigation purpose by considering three different cases of mobile robot's behavior for designing the behavioral controllers. The results showed that GA has good navigation ability.

In this paper, the genetic algorithm is used for designing process type plant layout problem with the aim of reducing material handling cost.

3. Problem Description

The study is based on the process layout which is one of type of plant layout where the arrangements of machines are made according to the type and nature of operations performed. In this type of layout, every work does not flow through same lines, but follows a different sequence of operations for achieving the final product. The layout design problem consists of assignment of machines in discrete locations with an aim of minimizing total material handling cost. The assignment cost is considered as the material handling cost which is the product of the distances between the locations and flow of materials between the department / machine. Different planning periods are considered for involving the dynamic market environment. Planning period describes quantity of different products to be manufactured according to the changing demand of customers. Based on these, material flow between the departments or machines is calculated. The mathematical model is formulated to minimize the material handling cost.

3.1 Assumptions of the model

Each facility location is considered as the coordinates of the department's centre in initial layout. All distances between the locations are calculated through Euclidean formula. The material flow cost for a unit product is assumed as a unit cost per unit distance travel. All departments are of equal area.

3.2 Mathematical model for plant layout problem

$$\text{Minimize } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} D_{ij} F_{ij} S_{ij} \qquad \text{Eq. (I)}$$

Where, Z = total material handling costs.
D_{ij} = distance between i[th] departments to j[th] departments.
F_{ij} = material flow between i[th] departments to j[th] departments.
S_{ij} = 1, i.e. Unit cost of travel of unit product for unit distance travel.
Where, S_{ii} & S_{jj} = 0
For calculating the distance between the locations, a Euclidian distance formula is used Palomo-Romero (2017).

$$\text{Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad \text{Eq. (II)}$$

Where, (x_1, y_1) and (x_2, y_2) is the coordinates of locations.
The total minimum material handling cost incurred on allocating machine to each location is calculated by

$$C_{ij} = \sum_{i,j}^{n} F_{ij}(\max) D_{ij}(\min) \qquad \text{Eq. (III)}$$

C_{ij} = Cost incurred for allocating machine to each location.
$F_{ij}(\max)$ = Maximum flow between the machines.
$D_{ij}(\min)$ = Minimum distance between the locations.

3.3 Proposed Genetic algorithm (GA) for layout formation

The genetic algorithm is an evolutionary optimization technique based on the ideas of natural selection and natural genetics. It is based on the "survival of the fittest" concept and simulates on the process of evolution. For a wide class of problem, GA gives better results Prasad et al (2014). GA works with initial solution, in this work, initial layout is considered as the initial solution for the algorithm. By using initial solution, the new solution is generated with an aim of improving the quality of the previous one. The operators such as selection, crossover and mutation were used to create the new solution. On the basis of fitness function value, the survivors were decided for the next generation.

The GA solver in the optimization toolbox describes stopping criteria which determine the causes to terminate the algorithm. There are some stopping criteria listed below:
Max iterations: represents the maximum number of iterations the algorithm performs.
Max function evaluations: specifies the maximum number of evaluations the algorithm performs for objective and constraint functions.
X tolerance: the termination tolerance for variable 'x'.
Function tolerance: represents the termination tolerance for the objective function value.
Nonlinear constraint tolerance: specifies the tolerance for the maximum nonlinear constraint violation.
Unbounded threshold: terminates iterations if the objective function value lies below it.

3.4 Pseudo code of Genetic algorithm

```
Begin
{
    Generate an initial population;
    Evaluate the population fitness;
    While (termination criteria not met)
    {
          Selection of parents for reproduction;
          Perform crossover and mutation operation;
Evaluate the population fitness;
}
}
```

3.5 Flow chart of Genetic algorithm

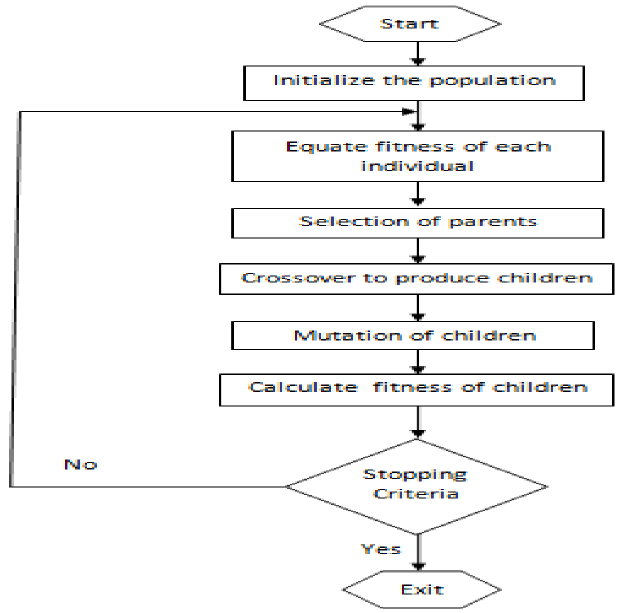


Figure 1. Flow chart of Genetic algorithm

4. Numerical Demonstration and Result Discussion:

The layout design problem consists of assignment of machines in discrete locations with the aim of minimizing the total material handling cost. The assignment cost is considered as the material handling cost which is the product of the distances between the locations and flow of materials between the department/machines.

The required data for the problem consists of a sequence of operations performed for different products, number of products manufactured in different planning horizon and location layout grid. An arbitrary layout is considered in evaluating the performance of layout formation method. The layout consists of six machines, i.e. M_A, M_B, M_C, M_D, M_E and M_F located at six locations L_1, L_2, L_3, L_4, L_5 and L_6 respectively. The initial layout is considered as under.

Table 1. Initial plant Layout

	L_1	L_2	L_3	L_4	L_5	L_6
M_A	1	0	0	0	0	0
M_B	0	1	0	0	0	0
M_C	0	0	1	0	0	0
M_D	0	0	0	1	0	0
M_E	0	0	0	0	1	0
M_F	0	0	0	0	0	1

These locations are generated arbitrarily in an area of (24X8) workspace in MATLAB software. The distance between each location with respect to the other is calculated by using Euclidian distance formula. These distances are represented through distance matrix shown in table 2. The sequence of machines employed in performing the operations on four different products, i.e. P1, P2, P3, and P4 is considered and on that basis, workflow between the machines is generated. For providing the dynamic market environment, dynamic demand of products is considered by employing multiple planning periods. Five different planning periods are considered to formulate the layout design problem and is shown in table 4. Each planning period describes the quantity of four different types of products manufactured.

Table 2. Distance matrix generated between locations

Locations	L_1	L_2	L_3	L_4	L_5	L_6
L_1	00.00	14.04	03.61	11.18	15.00	13.00
L_2	14.04	00.00	17.03	04.25	01.41	01.41
L_3	03.61	17.03	00.00	14.51	17.11	16.13
L_4	11.18	04.25	14.56	00.00	04.47	02.82
L_5	15.00	01.41	17.11	04.47	00.00	02.00
L_6	13.00	01.41	16.13	02.82	02.00	00.00

Table 3. Operation sequence of products on machines

Products	Operational sequence of machines
P_1	M_A - M_B - M_D - M_B - M_C - M_F
P_2	M_A - M_D - M_C - M_B - M_D - M_F
P_3	M_A - M_B - M_E - M_C - M_F
P_4	M_A - M_C - M_D - M_E - M_F

Table 4. Product demand (number of units) for the different planning period

Products	Products demand for Planning periods				
	1st period	2nd period	3rd period	4th period	5th period
P_1	30	25	15	05	10
P_2	25	40	20	20	25
P_3	15	20	35	15	30
P_4	20	10	25	45	15

From table 3 and table 4, work flow matrix between different departments is formed. The workflow depends upon the sequence of operations and the number of products manufactured in each planning period.

Table 5. Work flow matrix considering all planning periods

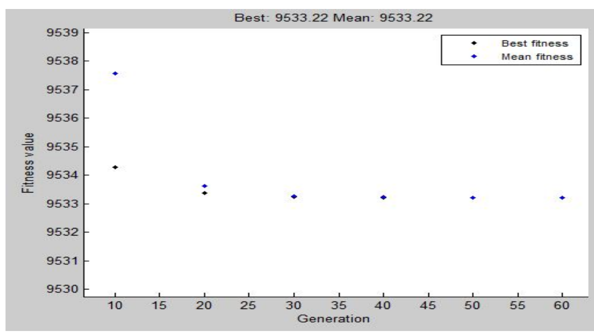
FROM \ TO	M_A	M_B	M_C	M_D	M_E	M_F
M_A		200	115	130		
M_B			85	215	115	
M_C		130		115		200
M_D		85	130		115	130
M_E			115			115
M_F						

Assume the cost of material handling for moving from one department to another as one unit per distance travel. The cost directly depends upon the total distance travelled between the machines. The total minimum cost matrix is generated on the basis of work flow matrix and distance matrix by using equation (III) for each allocation of machine at each location.

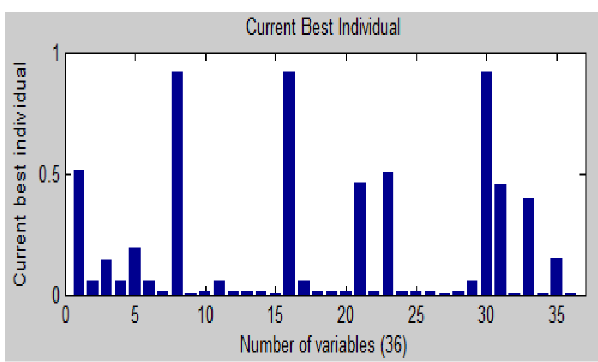
Table 6. Total minimum cost matrix

	L_1	L_2	L_3	L_4	L_5	L_6
M_A	3670.40	954.20	4469.75	1630.55	1056.10	866.30
M_B	3255.25	826.85	3822.00	1475.00	913.00	797.20
M_C	3670.40	954.20	4469.75	1630.55	1056.10	866.30
M_D	4611.00	2048.12	5664.60	2383.45	2232.00	1872.00
M_E	1700.00	324.30	2089.00	813.00	392.00	392.00
M_F	0.00	0.00	0.00	0.00	0.00	0.00

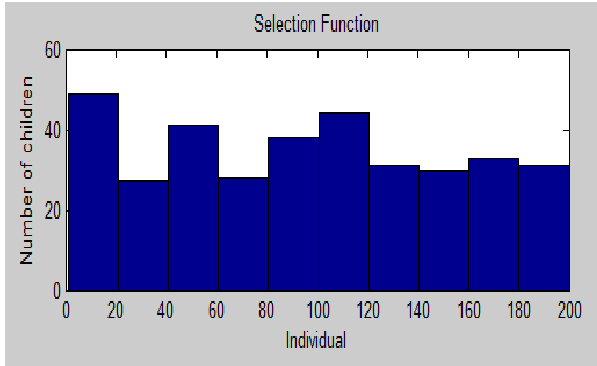
The Genetic algorithm (GA) solver in MATLAB is employed to solve the model. Population size is considered as 200. There are 36 variables considered for the purpose of allocation and 100 values of each variable are generated during iteration. Assuming a crossover fraction of 0.8 and considering all stopping criteria for termination of the algorithm, the following result is obtained.



(I)



(II)



(III)

Figure 2. (I) Best fitness chart; (II) Current best individual; (III) Selection function chart.

Table 7. Results obtained through GA solver

	L_1	L_2	L_3	L_4	L_5	L_6
M_A	0.52	0.05	0.13	0.05	0.20	0.05
M_B	0.02	0.92	0.00	0.01	0.05	0.01
M_C	0.02	0.01	0.00	0.91	0.05	0.01
M_D	0.01	0.01	0.45	0.01	0.51	0.01
M_E	0.01	0.01	0.00	0.01	0.05	0.92
M_F	0.42	0.00	0.45	0.00	0.13	0.00

Based on the results shown in table 7, allocations of machines are made on the different locations. This allocation is done where the variable has the higher proportionate value compared to the other variables in the respective row.

Table 8. Allocations made on the basis of GA results

	L_1	L_2	L_3	L_4	L_5	L_6
M_A	1	0	0	0	0	0
M_B	0	1	0	0	0	0
M_C	0	0	0	1	0	0
M_D	0	0	0	0	1	0
M_E	0	0	0	0	0	1
M_F	0	0	1	0	0	0

Table 9. Comparison of initial layout cost and proposed layout cost

Planning period	Initial layout cost	Proposed layout cost	% reduction in cost
1st period	2319.45	1769.75	23.67%
2nd period	2412.45	1739.55	27.89%
3rd period	2261.80	1708.05	24.48%
4th period	1951.25	1386.27	28.95%
5th period	1917.40	1399.70	27.00%
All planning periods	11742.15	8751.50	25.46%

The total material handling cost is calculated based on the allocations for each of the planning period. The corresponding percentage reduction in the proposed layout cost compared to the initial layout cost is obtained as described in table 9.

The result shows that for a fourth planning period, there is the maximum reduction in cost, i.e. 28.95%, whereas, the overall reduction in cost by considering all planning periods is achieved as 25.46%.

5. Conclusion:

In this work, a method for process type plant layout is proposed with the aim of reducing total material handling cost. Since material handling cost is one of the major contributors in increasing the cost of production. A robust layout procedure is developed for dynamic environment, where different demand scenarios are considered. Robust layout is fixed for different planning periods. This is being clearly shown in numerical illustration. Genetic algorithm (GA) solver is employed in MATLAB for optimizing the proposed process type plant layout. Further, result shows that the proposed method is able to reduce material handling cost significantly. This proposed method can further be applied to similar situations in industries with some or little modification. This work can be further extended by considering numerous decisive factors for the cost and constraints of floor area for similar types of small or large scale industries.

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