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ROW BASED LAYOUT DESIGN OF MEDIUM SIZE FLEXIBLE MANUFACTURING SYSTEMS

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ABSTRACT: The layout of a Flexible Manufacturing System (FMS) involves distributing different resources in the given FMS and achieving maximum efficiency of the services offered. With this in mind FMSs are designed to optimize production flow from the first stages as raw material to the finished product. Layout problems are known to be complex and are generally NP (non polynomial) hard. The problems of NP are not easily solvable within the deterministic time. The arrangement of workstations determines how long the materials have to travel and the associated material handling cost. Various heuristics and metaheuristics are used to solve NP hard problems. Out of these Genetic Algorithm (GA) and Ant Colony Optimization (ACO) are found to be effective metaheuristics to solve layout problems. Since the metaheuristics give a near optimal solution but not an accurate solution, for a large solution space, a single heuristic solution may not be appropriate especially when the number of workstations is large. Hence it is always important to obtain a solution for a layout problem by more than one technique like Genetic Algorithm, Ant Colony Algorithm. The objective of the present study is to find out the optimum FMS layout which yields minimum total transportation cost, by using Genetic Algorithm (GA) and Ant Colony Optimisation (ACO).

Keywords: Layout Design, Flexible Manufacturing Systems, Genetic Algorithm, Ant Colony Optimisation

1. INTRODUCTION

Layout problems are found in several types of manufacturing systems. Typically, layout problems are related to the location of facilities (e.g., workstations, departments) in a plant. They are known to greatly influence the system performance. The placement of the facilities in the plant area, often referred to as ‘‘facility layout problem’’, is known to have a significant impact upon manufacturing costs, work in process, lead times and productivity. A good placement of facilities contributes to the overall efficiency of operations and can reduce the total operating expenses. As a consequence, a tremendous amount of research has been carried out in this area during the last few decades. The layout of the FMS, that is, arrangement of the various workstations into rows, has a definite impact on the production time and cost, especially in case of large FMSs [1]. It was estimated that 20–50% of the manufacturing costs are due to handling of work pieces; by a good arrangement of workstations it is possible to reduce the manufacturing costs up to 10–30%. Some other authors report even higher percentage of material handling based costs. For example Chiang and Kouvelis report that 30–70% of total manufacturing costs may be attributed to the layout and material handling [2]. Therefore, in the early stage of designing an FMS itself, it is necessary to have an idea of the layout of the workstations. Genetic Algorithms (GAs) are adaptive heuristic search algorithms premised on the evolutionary ideas of natural selection and genetics. The basic concept of GAs is designed to simulate processes in natural system necessary for evolution; specifically those that follow the principles first laid down by Charles Darwin “Survival of the Fittest”. As such they represent an intelligent exploitation of a random search within a defined search space to solve a problem [3]. They make extensive use of artificial intelligence. First pioneered by John Holland in the 60s, Genetic Algorithms have been widely studied, experimented and applied in many fields in the engineering world. Not only does GA provide an alternative method to solving problem; it consistently outperforms other traditional methods in most of the problems. Ant behavior was the inspiration for the metaheuristic optimization technique the ant colony optimization algorithm (ACO), is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs [4].There are few evidences in the literature, where, more than one metaheuristics are used to determine the solution to a workstation layout problem. Also, much work has not been reported in the literature on the design of multi row FMS layouts.

Layout problems are known to be complex and are generally NP-hard. The problems of NP (non polynomial) exactness are the problems which are not solvable within the polynomial time [5]. Unfortunately, the complexity of the layout design problem increases exponentially as the number of workstations increases, since there are ‘n!’ different ways of arranging ‘n’ workstations into ‘n’ locations. The problem is also theoretically solvable by testing all possibilities (i.e. by blind search), but practical experience shows that in case of such manner of solving the capacities of either human or computer are quickly exhausted due to the great number of possible solutions. The arrangement of workstations determines how long the materials have to travel and the associated material handling cost. Workstations that handle materials heavily between them are placed close to each other to minimize the cost. This is easy if all the materials are processed on the workstations in a given order. But, if the order in which the workstations have to handle the materials is complex, it is a hard problem to solve. The layout design is a Combinatorial optimization problem that arise frequently in real life applications. Lawler defined combinatorial problems as "the mathematical study of finding an optimal arrangement, grouping, ordering or selection of discrete objects usually finite in numbers” [6]. It becomes more difficult to find a global optimum solution when the size of the combinatorial problem increases because the number of unique combinations increases exponentially with the number of objects. Also, many of the feasible solutions will have the same sub-optimal objective function value.

Layout problems rank among the hardest combinatorial optimization problems. Because of the complexity and the vast search space, conventional optimization methods, such as mathematical programming, dynamic programming and branch-and-bound are computationally infeasible. This situation has encouraged researchers to use heuristic search methods to find a near optimal solution with a reasonable computational effort.

In the present study optimum layout is found out by using GA and ACO applied to multi row layout problem.

2. THE FMS DESIGN

The determination of the layout and its evaluation is left to GA and ACO. Thus, in the first step, the sequence of the workstations is created by random numbers, whereas in the second step the actual layout with all dimensions is created with respect to the sequence and rules. Forming of the FMS with GA and ACO is divided into the following main steps-

- Acquisition of information needed for designing the FMS.
- Calculation of coordinates of workstations.
- Determination of distances between individual workstations.
- Calculation of value of cost function.
- Determination of layout by GA and ACO (determination of sequence of devices and number of rows).

For such manner of solving the problem it is necessary to know the dimensions of workstations and the minimum allowable distances between all the pairs of workstations. Further, it is necessary to know the transport quantities between the individual workstations during a certain time period. Also the variable transport costs depending on the transport means used must be known. We also need to know the width of transport (*w*), the greatest length of the row (*a*) and the width of the row (r) as shown in Fig. 3.

3. MATHEMATICAL MODEL

Most of the traditional methods for solving the facility layout problem assign facilities to the location of pre specified sites. This is discrete optimization approach. The workstations are arranged along well-defined rows because in most of the cases the separation between rows can be predetermined according to the type of the material handling system used, i.e, this problem can be viewed as discrete in one dimension and continuous in another dimension. Fig. 1 shows the parameters and decision variables for muti-row arrangement. Eq (1) represents the objective function and Eq (2) - Eq (6) are the constraints for the multi-row arrangement.

Objective function

$$Z = min \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} C_{ij} f_{ij} L_{ij} \quad (1)$$

$$\text{s.t} \left| x_i - x_j \right| Z_{ik} Z_{jk} \geq \frac{(l_i + l_j)}{2} + d_{ij} \quad (2)$$

$$y_i = \sum_{k=1}^{m} w\,(k-1)\, Z_{ik} \text{ for i= 1 to n} \quad (3)$$

$$\sum_{K=1}^{m} Z_{ik} = 1 \quad \text{for i= 1 to n} \quad (4)$$

$$\sum_{i=1}^{n} Z_{ik} < n \quad \text{k= 1 to m} \quad (5)$$

$$x_i,\ y_i >= 0 \quad \text{for i=1 to n} \quad (6)$$

$$Z_{ik} = 0, 1 \quad \text{for i=1 to n, k=1 to m}$$

when,
n is the number of workstations
m is the number of rows
w is the separation between two adjacent rows
d_{ij} is the distance between workstations i and j
f_{ij} is the frequency of trips between workstations i and j
c_{ij} is the transport cost per unit distance travelled between workstations i and j
l_i is the length of the machine i
x_i is the distance between the center of workstation i and the vertical reference line l_V, and Yi is the distance between the center of workstation i and the horizontal reference line l_H

Fig.1: Illustration of parameters and decision variables

3.1 Determination of Length of Paths

The coordinates of the points of operating the workstations are determined. When calculating coordinates the dimensions of the workstations (Table 1), the allowable distances between the adjacent workstations (d_{ij}) and the widths of the transport paths (w) are considered. Also the row width (r) equal to the width of the widest machine in that row is determined. Coordinates of the operating points are determined as shown in Fig. 2. According to Fig. 2 the matrix of rows and coordinates of operating points are obtained:

$$\begin{bmatrix} L_5 & l_3 & l_2 & l_4 & l_1 & l_6 \\ x_5 & x_3 & x_2 & x_4 & x_1 & x_6 \\ y_5 & y_3 & y_2 & y_4 & y_1 & y_6 \end{bmatrix}$$

when, x_i is the x coordinate of workstations i, and y_i is the y coordinate of the workstations i. Based on the values of the coordinates the matrix of lengths of transport paths between the individual workstations L_{ij}, can be determined. If several paths between workstations i and j are possible the shortest one is selected (Fig. 3).

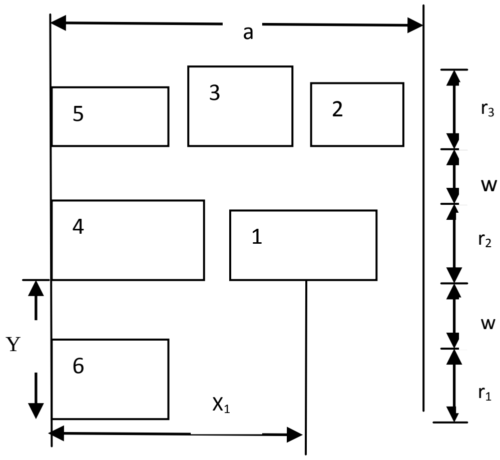

Fig. 2 : Representation of arrangement

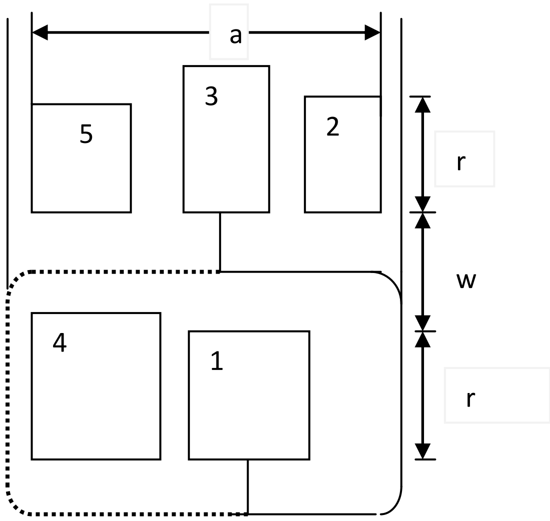

Fig.3: Determination of length of paths

When the workstations i and j are located in the same row the path length is determined according to the formula:

$$L_{ij} = |x_j - x_i| \quad (7)$$

When the workstations *i* and *j* are located in different rows the path length is determined by using the two formula given below:

$$^{1}L_{ij} = x_i + x_j + w + |y_j - y_i| \quad (8)$$

$$^{2}L_{ij} = (a - x_i) + (a - x_j) + w + |y_j - y_i| \quad (9)$$

From among the two lengths of paths the minimum path length L_{ij} is selected:

$$L_{ij} = \min({}^1L_{ij}, {}^2L_{ij}) \quad (10)$$

After calculating the shortest path between all pairs of machine workstations, the matrix Lij is obtained. The value of the fitness function for all organisms in the population can be calculated according eq (1), where f_{ij} is the frequency of trips between the workstations i and j, c_{ij} is the variable transport costs for the quantity unit, and L_{ij} is the length of path between the workstations i and j [7]. The number of workstations is equal to n. The costs of transport between two workstations can be determined if their mutual distance L_{ij} is known. During execution of the GA and ACO, the values f_{ij} and c_{ij} do not change, the value L_{ij} changes with respect to the mutual position of workstations and with respect to position in the arrangement (Eq 7 to Eq 9). To determine L_{ij}, the dimensions of the workstations, the minimum available distances between the workstations, the widths of the transport paths, and length of rows and coordinates of the points of operating workstations have to be known. Fitness function thus depends on the distances l_{ij} between the workstations. The distance between serving points is multiplied by coefficients f_{ij} and c_{ij} which measure the flow and the handling cost between workstations. The value of the cost function is thus the sum of all values obtained for all the pairs of workstations. The aim of the optimization process is to minimise this value. Fitness is based on the principle that the cost of moving goes up with the distance.

4. GENETIC ALGORITHM

Genetic Algorithm (GA) is a new approach to solving complex problems such as determination of facility layout; they can be defined as meta-heuristic based systems [8]. GA's became known through the work of John Holland in the 1960s. The GAs contains the elements of the methods of blind search for the solution and of directed and stochastic search and thus compromise between the utilization and search for solution. At the beginning, they search in the entire search space and afterwards, by means of crossover, they search only in the surrounding of the promising solutions. So GA's employed random, yet directed search for locating the globally optimal solution [3]. GA employs the vocabulary taken from the world of genetics itself, and as a result solutions refer to organisms (genotypes) of a population. Each organism represents the code of a potential solution to a problem and the changeover of this code to a real variable is called phenotype. An important characteristic of it is that GA's work by maintaining a population of potential solutions, whereas the other search methods process a single point of the search space. The typical steps required to implement GAs are encoding of feasible solutions into organisms using a representation method, evaluation of fitness function, selection strategy, setting of GAs parameters and criteria to terminate the process. Because of their properties, the GA were used for searching for the optimal (or near optimal) design of the FMS.

A generic description of the procedure followed in the GA algorithm is given as follows.

1. Determination of chromosome representation.
2. Determination of fitness function.
3. Determination of population size and number of generations.
4. Determination of genetic operators and their associated probabilities.
5. Determination of the termination criteria.

5. ANT COLONY OPTIMISATION

An ant algorithm is a recently developed, population-based approach which has been successfully applied to several NP-hard combinatorial optimization problems [4]. As the name suggests, ant algorithms have been inspired by the behavior of real ant colonies, in particular by their foraging behavior. One of the main ideas of ant algorithms is the indirect communication of a colony of agents, called (artificial) ants, based on pheromone trails. The (artificial) pheromone trails are a kind of distributed numeric information which is modified by the ants to reflect their experience while solving a particular problem. Recently, the Ant-Colony Optimization (ACO) meta-heuristic has been proposed which provides a unifying framework for most applications of ant algorithms to combinatorial optimization problems, a generic description of the procedure followed in the ACO algorithms is given as follows.

Machine Number	Dimensions of the workstations	
	Length(m)	Breadth (m)
1	5.0	3.0
2	2.0	2.0
3	2.5	2.0
4	6.0	3.5
5	3.0	1.5
6	4.0	4.0
7	2	2
8	6	3.5
9	3.5	3.0
10	4.5	4
11	2.5	2
12	5.5	3
13	3	2.5
14	2	1.5
15	4	3

Table1: Dimensions of the workstations

Step 1: initialization of the parameters and pheromone trails
Step 2: construction of a complete solution for each ant
Step 3: local pheromone trail update
Step 4: improvement of each solution to its local optimum
Step 5: global pheromone trail update
Step 6: if termination condition reached then stop otherwise go to step 2.

6. RESULTS AND DISCUSSIONS

6.1 Inputs

In the present work, a medium sized FMS layout consisting of fifteen workstations whose dimensions, distance between the workstations and frequencies of flow of parts is known is considered for analysis. The flow matrix and adjacency matrix are taken from the test problem [9]. The required dimensions of the workstations and the cost matrix are assumed since these are not given in the test problem. Table 1 gives the dimensions of the workstations. The adjacency table gives the distances between workstations if the workstations are placed adjacent to one another for different arrangement of workstations and the data is shown in adjacency table, Table 2. The cost of transportation per unit distance which means cost involved in transporting one unit from one workstation to another is given in cost table, Table 3 and flow of parts in number between workstations are shown in frequency table, Table 4.

For multi-row FMS applied to the 15 workstations problem row width r=4m and the distance between rows as w=4m.

Table 2: Adjacency table

0	1	2	3	4	1	2	3	4	5	2	3	4	5	6
1	0	1	2	3	2	1	2	3	4	3	2	3	4	5
2	1	0	1	2	3	2	1	2	3	4	3	2	3	4
3	2	1	0	1	4	3	2	1	2	5	4	3	2	3
4	3	2	1	0	5	4	3	2	1	6	5	4	3	2
1	2	3	4	5	0	1	2	3	4	1	2	3	4	5
2	1	2	3	4	1	0	1	2	3	2	1	2	3	4
3	2	1	2	3	2	1	0	1	2	3	2	2	2	3
4	3	2	1	2	3	2	1	0	1	4	3	2	1	2
5	4	3	2	1	4	3	2	1	0	5	4	3	2	1
2	3	4	5	6	1	2	3	4	5	0	1	2	3	4
3	2	3	4	5	2	1	2	3	4	1	0	1	2	3
4	3	2	3	4	3	2	2	2	3	2	1	0	1	2
5	4	3	2	3	4	3	2	1	2	3	2	1	0	1
6	5	4	3	2	5	4	3	2	1	4	3	2	1	0

Table 3: Cost table

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

6.2 Application of GA for Multi Row Optimal Layout

The parameters of GAs depend largely on the characteristics of each particular problem [3]. In spite of that the guidelines for selection of evolutionary parameters can be defined. The methodology that is adopted to select the parameters for GA is sensitivity analysis. The values of evolutionary parameters were:

- Probability of crossover Pc = 0.7
- Probability of mutation Pm = 0.3
- Population size P = 180.
- Number of generations G = 700.

The parameters for multi-row are:
a = 31m, r = 4m, w = 4m.

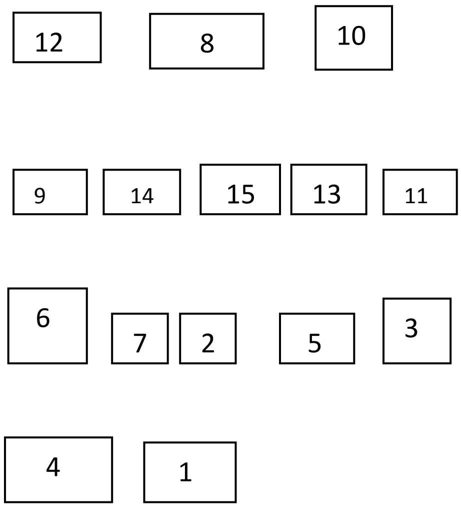

Fig. 4: Optimum arrangement of workstations

Table 4: Frequency Table

0	20	20	40	70	20	10	0	10	30	0	0	10	0	20
20	0	10	60	140	40	0	20	20	0	40	20	0	30	0
20	10	0	20	30	30	50	40	0	10	0	10	30	20	0
50	60	20	0	50	60	40	40	30	0	0	20	0	0	30
70	140	30	50	0	80	70	30	20	30	10	0	20	30	0
20	40	30	60	80	0	60	30	30	0	30	20	40	0	20
10	0	50	40	70	60	0	20	120	10	0	30	10	40	0
0	20	40	40	30	30	20	0	10	70	40	30	0	30	0
10	20	0	30	20	30	120	10	0	30	100	60	20	10	20
30	0	10	0	30	0	10	70	30	0	60	50	30	30	10
0	40	0	0	10	30	0	40	100	60	0	20	100	50	70
0	20	10	20	0	20	30	30	60	50	20	0	20	90	50
10	0	30	0	20	40	10	0	20	30	100	20	0	10	90
20	0	0	30	0	20	0	0	20	10	70	40	90	80	0
0	30	20	0	30	0	40	30	10	30	50	90	10	0	80
20	0	0	30	0	20	0	0	20	10	70	40	90	80	0

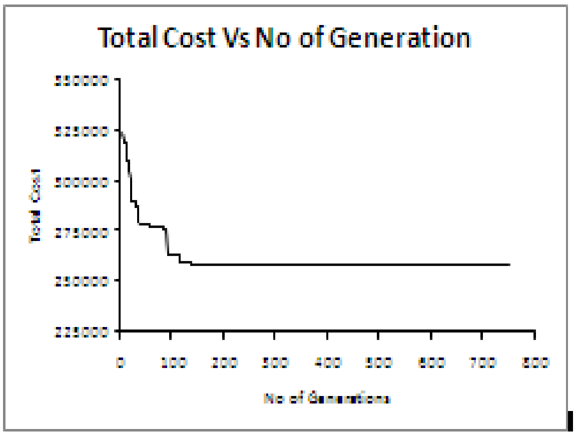

Fig.5: Variation of cost with number of Generations

Fig. 5 shows the results of all generations for the multi-row FMS layout. From the results obtained from GA it has been observed that, at 137th iteration optimum transport cost of Rs.257,928 is obtained. When GA is applied to the 15 workstation multi-row FMS layout the optimum sequence obtained was 12 -8 -10- 9-14- 15- 13- 11- 6- 7- 2 -5 -3 -4- 1 and the corresponding total cost was found to be Rs.257,928. Fig. 4 shows the optimum arrangement of 15 workstation multi- row FMS layout using GA.

6.3 Application of ACO for Multi-Row for Optimal Layout

The same data which was used to obtain a solution for Multi-row 15 workstation problem by applying GA, has been used to obtain a solution by applying ACO also.

The parameters for applying ACO are
No of ants, na = 5,
Number of iterations, ni = 550,
Parameter determining the influence of pheromone trail strength on probability of selection α =1,

Parameter determining the influence of heuristic information on probability of selection β=-1,
Pheromone trial evaporation factor ρ=0.1,
Pheromone trial evaporation factor ξ=0.9,

Initial pheromone trail strength $\tau_{ij}(1)$ = 0.02 and

Quality of pheromone per unit distance Q = 3000.

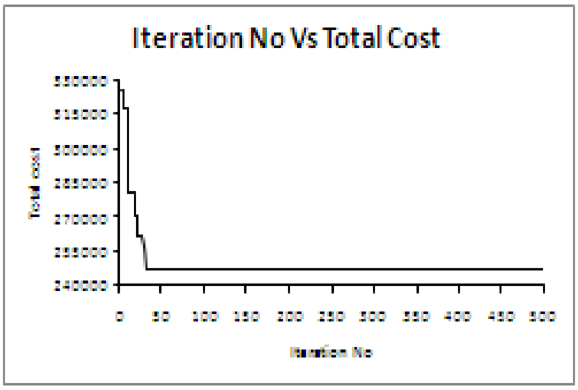

Fig. 6: Variation of cost with number of iterations

Fig.6 shows the results of all iterations for the multi-row layout by applying ACO. From the results obtained from ACO it has been observed that, at 22nd iteration optimum transport cost of Rs.278022 is obtained. In case of ACO the optimum sequence obtained 11- 8- 10- 9- 13- 14- 15- 12- 7- 2- 5- 4- 6- 3- 1 and the corresponding total cost was found to be Rs.278688.

7. CONCULSIONS

This section represents computatiion results by the GA algorithm and ACO algorithm for medium sized multi row FMS for the tested problem. The results have been presented in Fig. 5 by GA and Fig. 6 by ACO for multi-row FMS.

GA and ACO techniques have given different results when they have been applied to 15 workstation multi-row FMS layout. When GA is applied to the 15 workstation multi- row FMS layout the optimum sequence obtained was 12 -8 -10- 9- 14- 15- 13- 11- 6- 7- 2 -5 -3 -4- 1 and the corresponding total cost was found to be Rs.257928. In case of ACO the optimum sequence obtained 11- 8- 10- 9- 13- 14- 15- 12- 7- 2- 5- 4- 6- 3- 1 and the corresponding total cost was found to be Rs.278688. Thus GA approach has given minimum transportation cost of Rs.257928 for 15 workstation multi-row FMS layout problem for an optimum sequence of 12 - 8 - 10- 9- 14- 15- 13- 11- 6- 7- 2 - 5 - 3 - 4- 1.

The validity of the models is tested by building models in FLEXSIM software incorporating the characteristics of the medium sized FMS and results have shown that the results obtained by GA and ACO are in concurrence with the simulation results. Thus by means of the presented model the optimum layout of the workstations of medium sized FMS can be found. The model searches for the optimum layout in rows and finds itself the optimum number of rows.

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