OPTIMISATION OF LAYOUT OF MACHINES IN A FLEXIBLE MANUFACTURING SYSTEM

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Abstract One of the issues related to a facility layout's problem in a flexible manufacturing system involves positioning of machines in a cell so as to minimize the distance of material flow between the machines of the layout. The problem of finding the optimum layout is hard and hence the deterministic techniques are not computationally feasible. This paper discusses the use of Genetic Algorithm in solving the problem of layout of machines in a flexible manufacturing system. It has been assumed that any machine of the cell can be placed in any of the places reserved for positioning the machine. Dijkstra Algorithm or more popularly known as A* Algorithm has been suitably modified to compute the optimum path and the distance traveled by an autonomous vehicle in the vicinity of the machines. Such autonomous vehicles considered in the present work are used for carrying cutting tools whereas the parts are being transported using independent material handling system depending upon the layout configuration.

Keywords: Genetic algorithm, A* algorithm, Autonomous vehicle, Facility planning.

INTRODUCTION

Facility layout design has been the subject of an interdisciplinary interest for over two decades. The process of developing facility layout contains the elements of both art and science. It is usually viewed as an optimization problem and the best facility layout is found out by optimizing some measure of performance subjectED to some constraints. To date, significant progress has been made in manufacturing technology and a large number of flexible manufacturing systems (FMS) have been implemented around the world. Optimal design of the physical layout of a manufacturing system is one of the most important issues that must be resolved in the earlier stages of the system design. Cost consequences of the layout decision can be observed during the implementation as well as the operation of the system. Good solution to these problems provide a necessary foundation for effective utilization of the system. This paper addresses the flexible manufacturing system layout problem by assuming that the number and types of machines in a cell are known in advance.

The authors in their earlier work [2] [3] successfully adopted the Dijkstra Algorithm which is popularly known as A* Algorithm for simulation of motion path planning of mobile robots in the vicinity of obstacles.

In the present work, the same as been suitably adopted to determine the path and distance to be traveled by an autonomous vehicle/autonomous tool carrier for transferring the cutting tools from one machine to another of the layout.

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METHODOLOGY

Genetic Algorithms (GAs) are stochastic search techniques based on the mechanism of natural selection and natural genetics. Genetic Algorithms start with an initial set of random solutions called population. Each individual in the population is called chromosome representing a solution to the problem under consideration. A chromosome is a string of genes (symbols). The chromosomes evolved through successive iteration is called generation. During each generation, the chromosomes are evaluated using some measure of fitness. To create the next generation, new chromosomes called offsprings are formed either by using a crossover operator or mutation operator or both.

A new generation is formed by selecting a few chromosomes and rejecting a few chromosomes according to some fitness values to keep the population size constant. Fitter chromosomes have higher probabilities of being selected. After several generations, the algorithm converges to the best chromosome, which hopefully represents the optimal or sub optimal solution to the problem.

The problem of finding the solution to the arrangement of machines in the layout of a flexible manufacturing system is formulated as a genetic algorithm problem and solved as follows:

i. The chromosomes are identified as ordered position of machines in the layout.
ii. The genes (symbols) are identified as the individual machine numbers of the layout.
iii. The initial population has been generated randomly.
iv. The total distance traveled by each part type in the layout has been considered as the objective function.
v. Selection of chromosome for reproduction has been done by evaluating the fitness value obtained from the objective function.
vi. Selection of chromosomes for crossover has been done by using Partially Mapped Crossover operator followed by mapping and legalizing the off springs.
vii. Selection of chromosome for mutation has been done by using Displacement Mutation operator.
viii. The chromosome with optimum value of objective function after all iterations has been considered as the solution to the problem of finding the optimum position of machines in the layout.

The problem of motion path planning of an autonomous vehicle (Tool carrier) in the vicinity of machines of the layout has been transformed to one of graph searching. This has been done by considering all corner point's of the machines and load / unload points of each machine as nodes. A connectivity graph for the autonomous vehicle has been constructed by joining each of the nodes to each of the approachable nodes. Thus constructed non-directed graph has been searched for the shortest path using A* algorithm. By adopting these steps an optimal path for the autonomous vehicle has been generated and used for its movement from source to destination in the vicinity of machines of the layout. The part transfer and tool transfer handling systems have been assumed to work independently.

ILLUSTRATION

a) Optimization of layout of machines

A flexible manufacturing system with an open field layout having 9 machines has been considered. The initial arrangement of machines has been shown in the figure1 where S1 to S9 refers to the slots of the layout to accommodate the machines M1 to M9. The clearance between any two adjacent machines is taken as 2 units.

The number of part types and their sequence of operation is shown in table-1. The distance between any two machines of the layout for a particular arrangement of machines as shown in the figure-1 is presented in the table-2. The distance between load/unload points and the machines of the layout is also presented in the table-2.

The objective function refers to the distance traveled by the parts and is calculated for the particular arrangement using the following equation:

Objective function = $L_i + \Sigma D_{ij} + U_j$

Where L_i=distance between load point and ith machine
D_{ij}=distance between ith and jth machine
Uj=distance between unload point and jth machine

By following the standard procedure of genetic algorithm the results obtained after 50 iterations are presented in the table-5. It is evident from table-5 that the optimum solution to the problem having minimum distance traveled (158 units) refers to the chromosome 753641298. Hence the optimum solution to the problem is to allocate machine M7 to slot S1, M5 to S2, M3 to S3, M6 to S4, M4 to S5, M1 to S6, M2 to S7, M9 to S8, M8 to S9.

b) Motion path planning of autonomous vehicle in the proposed layout

Two machines, M1and M2 have been considered to illustrate the computation of path planning of autonomous vehicle. Consider two triangular machines (M/C– 1 and M/C – 2) as shown in figure-2 with P_1, P_2, P_3 being the co-ordinates of the vertices of M/C-1 and P_4, P_5, P_6 being the co-ordinates of the vertices of M/C –2. Let S_1 and D_1 be the source and destination co-ordinates respectively of the autonomous vehicle.

The problem of path planning for the autonomous vehicle has been approached in two phases as follows:

In the first phase the machine dimensions are mapped taking into consideration the dimension of autonomous vehicle. By this, the machine dimensions are apparently increased and consequently the free workspace is apparently reduced.

In the second phase, the co –ordinates of the mapped vertices of machines n_1, n_2, n_3, n_4, n_5, n_6 and the co-ordinates of the source and destination of the autonomous vehicle is considered as nodes. A connectivity graph has been constructed for the autonomous vehicle by joining each of the nodes to each of the approachable nodes. This connectivity graph has been searched for shortest path using Dijkstra algorithm.

Table 1: Sequence of operation for part types

PART TYPE	MACHINE SEQUENCE
P1	1 3 4 6 8 9
P2	2 4 5 3 6 9

Table 2: Inter distance between machines and distance between

M/C IN SLOT	M7	M5	M3	M6	M4	M1	M2	M9	M8
M7	---	8	12	6	10	14	20	24	24
M5	8	---	8	10	6	10	24	24	20
M3	12	8	---	14	10	6	24	20	16
M6	6	10	14	---	12	16	6	10	14
M4	10	6	10	12	---	12	10	6	8
M1	14	10	6	16	12	---	14	10	6
M2	20	24	24	6	10	14	---	18	12
M9	24	24	20	10	6	10	8	---	8
M8	24	20	16	14	10	6	12	8	---
Load	12	16	20	14	16	20	12	16	20
Unload	14	18	22	12	16	20	10	14	18

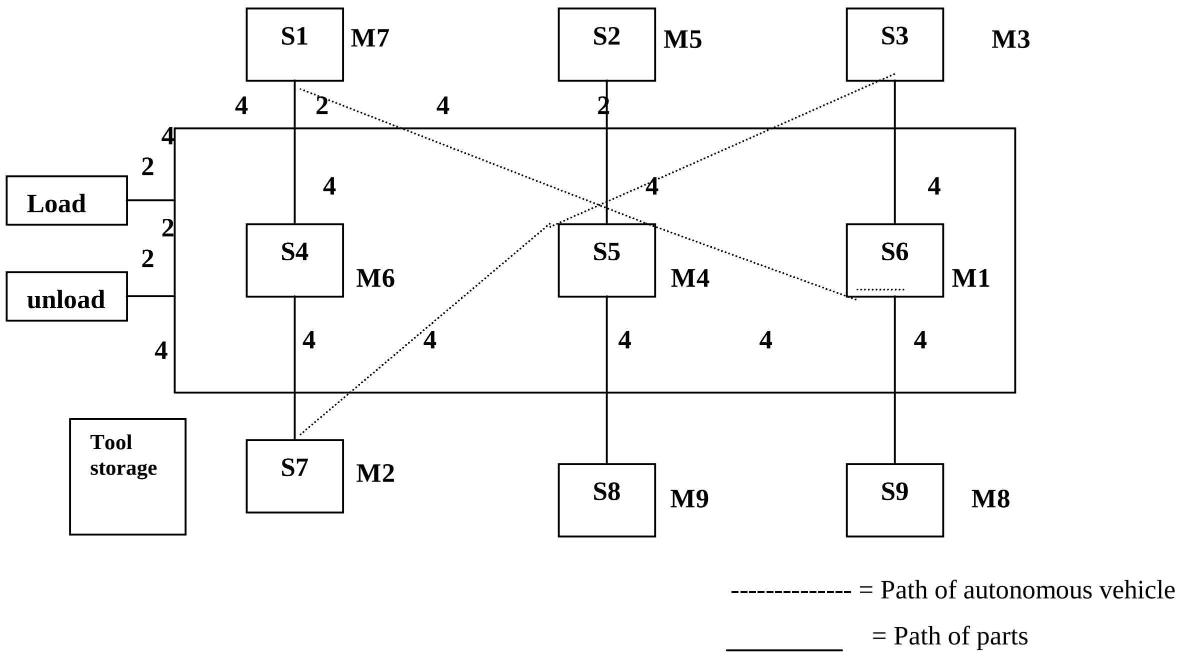

Fig.1 Openfield layout with machine positioned in various slots

Table.5: Results for the first nine iterations and the

NUMBER OF ITERATION	OBJ. FN.	CHROMOSOMES	RAWFITNESS	PBTY OF SELECTION
1	214	765142839	0.000023	0.029607
2	208	841235679	0.000030	0.029336
3	192	469583712	0.000068	0.135361
4	182	921738546	0.000112	0.219847
5	174	785364129	0.000167	0.327972
6	172	465983712	0.000184	0.216472
7	170	867915243	0.000203	0.233189
8	162	137568429	0.000304	0.413152
9	160	924865731	0.000335	0.384463
:	:	:	:	:
:	:	:	:	:
:	:	:	:	:
50	158	753641298	0.000371	0.408863

Let the x and y co- ordinates of the machine vertices after mapping, source and destination co-ordinates of autonomous vehicle in specific units be as follows:
Co- ordinates of vertex n_1= 96; 84
Co- ordinates of vertex n_2= 96; 132
Co- ordinates of vertex n_3= 138; 132
Co- ordinates of vertex n_4= 132; 36
Co- ordinates of vertex n_5= 132; 96
Co- ordinates of vertex n_6= 168; 36
The source co- ordinates of autonomous vehicle
S_1= 60; 84
The destination co-ordinates of autonomous
vehicle D_1= 174; 48
The centers of the autonomous vehicle is made to coincide with its source. The source co- ordinate of the autonomous vehicle is numbered as n_0 and the destination co- ordinate of autonomous vehicle is numbered as n_7. Thus for autonomous vehicle, n_0 is (60,84) and n_7 is (174,48).

The procedure for using Dijkstra Algorithm to determine the shortest path for autonomous vehicle has been done by creating two tables, namely link table and distance table. The link table as shown in the table-3 indicates the distance between any two approachable nodes

The distance table as shown in the table-4 has been created by computing dist [i] where dist [i] represents the distance of any node i from the source of the autonomous vehicle. The details of table-4 has been computed as follows:

Step 1. Select node U (were U refers to node number) that has minimum dist [V] value (V range from 1 to 7 in this case).

Step 2. If dist [V] > {dist [U] + link [U] [V]} is TRUE for V ranging from 1 to 7 and U corresponds to the node number selected in the Step1, then store the value of right hand side of the above inequality in the dist [V]. This is to facilitate the identification of the shortest path at the end of all iterations.

If dist [V] > {dist [U] + link [U] [V]} is false then do not update the value of dist [V].

Step 3. Repeat Step 1 and Step 2 until node 7 is selected. This indicates that the autonomous vehicle has reached the destination. This is the end of iterations.

Step 4. To find the shortest path between source and destination for the autonomous vehicle start from the last iteration of the Table-3. Select the south – east cell i.e., the bottom most cell of the dist [7] which represents the destination node. Check whether dist [7] column value has changed and the node selected at this iteration gives the first preceding via point. In this case it is node 6 and hence the node 6 is selected as first via point. Repeat the above procedure for the dist [6] column. In this column the change has taken place in the 4th iteration and the node selected is node 4. Hence node 4 is selected as second via point. Repeat the same procedure for dist [4] column, which results in selection of node0 as the third via point and which itself is the source point. Hence the path of autonomous vehicle is found backward as

$n_7 \longrightarrow n_6 \longrightarrow n_4 \longrightarrow n_0$

As n_0 corresponds to S_1 and n_7 corresponds to D_1 the shortest path of the autonomous vehicle is

$S_1 \longrightarrow n_4 \longrightarrow n_6 \longrightarrow D_1$

and the distance traveled by autonomous vehicle is 136 units as indicated by Table –3.

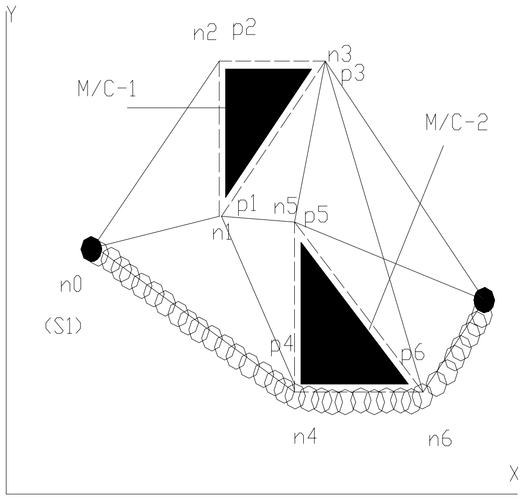

Fig.2 motion path planning of autonomous vehicle

Table.3: link table showing the distance between approachable nodes of machines

Nodes	0	1	2	3	4	5	6	7
0	0	36	60		87			
1	36	0	48	64	60	38		
2	60	48	0	42				
3		64	42	0		36	101	91
4	87	60			0	60	36	
5		38		36	60	0	70	64
6				101	36	70	0	13
7				91		64	13	0

Table.4: Distance table indicating the value of dist [ ] at each iteration.

Iter no.	Nodes selected	Nodes visited earlier	Dist [1]	Dist [2]	Dist [3]	Dist [4]	Dist [5]	Dist [6]	Dist [7]
-	0	-	36	60		87			
1	1	0	36	60	100	87	74		
2	2	0,1	36	60	100	87	74		
3	5	0,1,2	36	60	100	87	74	144	138
4	4	0,1,2,5	36	60	100	87	74	123	138
5	3	0,1,2,5,4	36	60	100	87	74	123	138
6	6	0,1,2,5,4,3	36	60	100	87	74	123	136

The movement of autonomous vehicle in the layout under consideration, from machine 6 to machine1 and from machine7 to machine3 has been shown in the figure-1

CONCLUSION

Genetic algorithm being used to solve a variety of function optimization problems has been successfully used to solve the problem of layout of machines in a flexible manufacturing system. An open field layout with nine machines has been considered for illustration to find the optimum position of the machines in the layout. However the other layout configuration like line, loop and ladder can also be solved using the proposed methodology. Dijkstra algorithm, more popularly known as A* algorithm has been suitably modified to compute the optimum path and distance traveled for the autonomous vehicles being used in the flexible manufacturing system for movement from one machine to another machine by avoiding collision.

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