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Integrated Layout Design Approach for Cellular Manufacturing System Environment

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Abstract: Traditionally, the design of physical layout of the manufacturing system, I/O station location determination and subsequently the design of Material Handling System (MHS) is being carried out in isolation. In this work an attempt is made to concurrently design 1. Cell System Layout (CSL) or Inter-cell layout, 2. Determining optimum location of input, output (I/O) stations of each cell and 3.The flow path of the MHS using a Genetic Algorithm based methodology for a Cellular Manufacturing System (CMS) environment under open field configuration. The proposed algorithm is employed to optimize one of the classical objective namely Total Material Handling Cost (TMHC). The algorithm is tested on four different bench mark layouts and with different initial problem data sets. It is found that the proposed algorithm is able to produce satisfactory solutions consistently within a reasonable computational limit.

Key words: Integrated layout design, genetic algorithm, open-field configuration

INTRODUCTION

Facility layout design is an important issue for any industry, as a poor layout may degrade overall efficiency of the production system. Traditionally, the researchers and designers design sequentially first the Inter-cell layout (Cell system layout-CSL), that is the relative location of each facility or department of the system primarily to minimize the inter-cell movements of the parts being processed and subsequently design the Material Handling System (MHS), the material flow path between the departments to minimize the unit transportation cost. As the CSL and MHS design are performed sequentially and separately, the design procedure invariably leads to solution that can be far from the total optimum (Ho and Moodie, 2000). Many algorithms for cell formation have been developed for the past three decades in cellular manufacturing. In the recent years researchers have focused on concurrent design of both CSL and MHS design by adopting integrated approach. Kim and Kim (1998) mentioned the difference between traditional block layout problem and layout design problem in CMS. Hassan (1995) reported the two important differences between traditional block layout problem and layout design in cellular manufacturing are specific cell shapes with known dimension and predefined local coordinates of input/output (I/O) stations of the cells on the sides of the rectangular shaped departments. We cannot make use of the procedures that are suitable for traditional block layout problem to CSL problems. Only those procedures for solving the facility layout of predetermined shapes can be applied to CSL problems.

Ho and Moodie (2000) emphasized concurrent layout design of cell system layout and flow paths to avoid the aforementioned drawbacks of traditional layout methods. An integrated approach to the optimal location of manufacturing facilities and material handling system design is proposed by Aiello *et al.* (2002). They used flexible bay structure as layout representation method and utilized GA as optimization tool. For the objective calculation the distance between I/O points is measured along the department perimeter. In the work by Hu *et al.* (2007) a Sequence Pair (SP) representation is utilized for integrated layout design problem where perimeter distance is used for cost calculation. They solved it using GA. Taghavifard *et al.* (2009) proposed a GA based approach to schedule machines and AGV simultaneously in and FMS configuration. A GA based Bi-criteria integrated layout design optimization problem is proposed by Jerin Leno *et al.* (2011) for the CMS environment under open field configuration.

Owing to computational complexity very little work has been done to solve Cell System Layout (CSL) and flow path design problem simultaneously. Slicing Tree Structure (STS) and flexible bay representation have been broadly used for layout design problem in the literature. Sequence Pair (SP) representation technique proposed by Murata *et al.* (1996) for VLSI floor planning problem can handle cells of specific shapes and predefined I/O points for facility layout problem in CMS. For the evaluation of

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sequence pair, they construct the constraint graphs Gh and Gv followed by longest path searches. Relatively simpler and efficient algorithm for SP evaluation is proposed by Xiaoping *et al*. (2000). They proposed an algorithm for calculating the spatial coordinates of cells to be placed on a two dimensional planar region for VLSI floor planning problem. In their work they reported that the Longest Common Subsequence (LCS) based sequence pair evaluation technique outperforms graph based evaluation technique for small to very large size bench mark circuits. Among the commonly used layout configurations such as spine, circular, ladder and open-field layout, the open-field type layout configuration is attempted to solve in this research work.

In this study, an attempt is made to concurrently design, (1) Cell System Layout (CSL) or Inter-cell layout, (2) Determining optimum location of input, output (I/O) stations of each cell and (3) The flow path of the MHS using a Genetic Algorithm based methodology for a Cellular Manufacturing System (CMS) environment under open field configuration. The proposed algorithm is employed to optimize one of the classical objective namely Total Material Handling Cost (TMHC).

PROBLEM DESCRIPTION

There are N number of cells which are to be placed in a production floor layout of width W and height H. The cells are considered to be rectangular blocks with known dimension. Given the width and height of the individual cell (determined by size and shape of the facilities/machines), quantum and frequency of material flow between the cells, the aim is to find the exact location (x and y coordinates), the orientation of the individual cells, the spatial coordinates of input and output stations (in this study I/O stations are assumed to be located in the middle of the edges of rectangular cells) and to decide the shortest flow path distance between the cells (along the department perimeter) with the objective of minimizing the TMHC.

The mathematical model for the integrated layout design problem is formulated based on the model represented by Hu *et al*. (2007) and shown below:

Subject to:

$$\text{Minimize TMHC} = \sum_{i=1}^{N}\sum_{j=1}^{N}(c_{ij}\ f_{ij}\ d_{ij}) + P \quad (1)$$

$$x'_i = x_i+(1-u_i)w_i+u_ih_i \quad \forall i \quad (2)$$

$$y'_i = y_i+(1-u_i)w_i+u_iw_i \quad \forall I \quad (3)$$

$$\begin{aligned} x_i^{I(O)} = {} & x_i + (1-u_i)(1-v_i)I(O_i^x) \\ & + I(O_i^y)u_i\,(1-v_i) \\ & + (w_i - I(Q_i^x))\,(1-u_i)v_i \\ & + (h_i - I(O_i^y))u_iv_i \ \forall i \end{aligned} \quad (4)$$

$$\begin{aligned} y_i^{I(O)} = {} & y_i + (1-u_i)(1-v_i)I(O_i^y) \\ & + (w_i - (O_i^x)u_i\,(1-v_i) \\ & + (h_i - I(Q_i^y))\,(1-u_i)v_i \\ & + I(O_i^y))u_iv_i \ \ \forall i \end{aligned} \quad (5)$$

$$l_{ij}+l_{ji}+b_{ij}+b_{ji}\geq 1 \quad \forall I \quad (6)$$

$$x'_i\leq l_{ij}x_j+W(1-l_{ij}) \quad \forall i<j \quad (7)$$

$$y'_i\leq b_{ij}y_j+H(1-b_{ij}) \quad \forall i<j \quad (8)$$

$$x'_i,\ y'_i,\ x_i^{I(O)},\ y_i^{I(O)}\geq 0 \quad \forall i \quad (9)$$

$$u_i,\ v_i\in\{0,1\} \quad (10)$$

$$l_{ij},\ b_{ij}\in\{0,1\} \quad (11)$$

where, $P = \alpha(P_w+P_h)$ is a penalty term the guarantee that the layout solution satisfies the following floor boundary condition $x'_i\leq w\forall i$, $y'_i\leq H\forall i$:

$$P_w = \max\left\{0, \max_i\{x'_i\} - w\right\},\ P_h = \max\left\{0, \max_i\{y'_i\} - H\right\}$$

α = The weight of penalty and was set to be algebraic sum of flow interaction between each pair of cells

Constraints 2 and 3 define the x-coordinate of the right boundary and the y-coordinate of the upper boundary of each cell. Constraints 4 and 5 are used to specify the x and y coordinates of I/O stations for each cell. These coordinates are expressed in generalized terms with respect to the lower-left corner point of the cell under the horizontal configuration that is before considering rotation. Constraints 6-8 are to ensure that there is no overlap between any pair of cells by letting each pair of cells be separated in the *x* or *y* direction. Constraints 9-11 specify the bounds for each variable.

PROPOSED METHODOLOGY

In this study, a simple GA is proposed to obtain the best feasible solution which minimizes TMHC.

Solution representation: In a GA approach feasible solutions to the problem are encoded into a string of

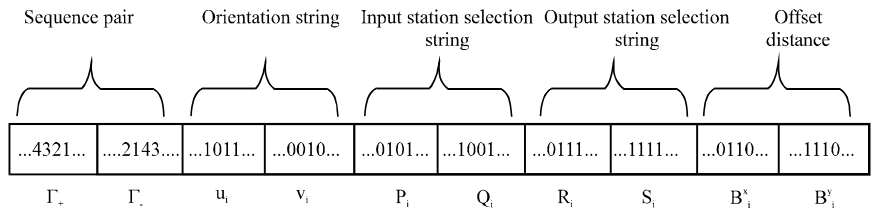

Fig. 1: Chromosome structure

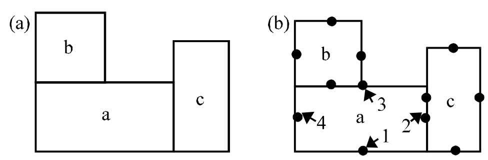

Fig. 2(a-b): (a) CSL for SP = (bac; abc) and (b) CSL with four candidate I/O stations located at the midpoint of each side

decision choices that resemble chromosomes. The chromosome that represents a feasible solution is shown in Fig. 1.

The chromosome string consists of five parts. For a layout problem of N cells, the first part is first and second sequence (Γ_+ and Γ_-) of sequence pair, the second part is binary code of 2N bits that represents u_i and v_i of each cell, the third part is binary code of 2N bits that is used to select one input station out of four candidate input station points which are present at the midpoint of four sides of the cell, the fourth part is for finding the output station of a cell by adopting the same procedure explained for input station and the last part is 2N bytes which helps to define the offset distances in the x direction and y direction for each cell. The offset distances Δx_i and Δy_i for cell i are determined as follows: $\Delta x_i = (B^x_i/255)*\Delta X$ and $\Delta y_i = (B^y_i/255)*\Delta Y$. Where ΔX and ΔY are two preset constants and are problem dependant. In this study, they are set such that:

$$\Delta X = \Delta Y = \min\{\min_i\{w_i\}, \min_i\{h_i\}\}$$

Sequence-pair representation: A Cell System Layout (CSL) can be represented by a unique sequence pair (Murata *et al*., 1996) describing the topology of the cell placement. A layout consisting of cells (a,b,c). The dimensions for every cells are: a(10_×5), b(5×5), c(4×8) and it's corresponding CSL is shown in Fig. 2a which can be represented by a SP = (bac; abc). This SP defines the relative positions of the cells in the CSL. Consider cells a and c in the SP, in both the sequences the order of a precedes c and so in the CSL a is to the left of cell c. Similarly between cells b and c, the order of b precedes c in both the sequences and so b is to the left of cell c. Consider cells a and b, in first sequence b proceeds a and in the second sequence a proceeds b indicates there is no horizontal relationship between cell a and cell b. As in the first sequence b proceeds a and so in CSL location of cell b is above cell a. For each cell the four candidate I/O station located at the midpoint of the department periphery is shown in Fig. 2b.

Fitness evaluation: The decoding of a chromosome and finding the objective function value for a feasible solution is done in three steps:

Step 1: Using first and second part of the chromosome and the sequence pair evaluation algorithm Algorithm 1 found in the literature (Xiaoping *et al*., 2000).The spatial coordinates of the lowest left corner of each cell in a CSL is computed

Step 2: Once the spatial coordinates of the cells are found, four candidate I/O station at midpoint of each side of a cell is determined. Using third/fourth (Input station selection string/output selection string) in the chromosome, one out of four candidate Input (Output) station point is selected as input station (output station) of a cell

Step 3: And then the grid graph (Hu *et al*., 2007) is constructed and then through repeated applications of Dijkstra's algorithm (Cormen *et al*., 1990) the shortest path distance along the department perimeter is determined. The obtained shortest path distance d_{ij} along the department perimeter is unique for corresponding CSL

Step 4: Calculation of the objective function value using Eq. 1

GA operators

Selection: The selection module is constructed on the basis of Roulette wheel (Kochhar *et al*., 1998) mechanism. The probability of selection for each chromosome is based on a fitness value relative to the total fitness value of the population. The selection module ensures reproduction of more number of highly fit chromosomes compared to the number of less fit chromosomes.

Crossover: The crossover operation is exercised on the chromosomes of the intermediate population with a probability, known as crossover probability (p_c). The crossover operator of GA is problem dependent. For the first part, a crossover operator similar to Kochhar *et al.* (1998) was implemented for first and second sequence of the sequence pair independently. The first child is constructed by randomly picking a gene from the first parent and placed it in a child string at the same location as its position in the parent sequence. This process is continued for k cells where k is proportional to the relative fitness of the first parent. The missing integers in the first child are filled in the same order as they appear in the second parent. Similarly the second child string is created by reversing the selection order of two strings. For remaining four parts (orientation, input station selection, output station selection and offset distance) of the chromosome, a heterosexual one-point crossover (Riccardo and Langdon, 1997) was adopted. An example of this crossover operator is shown in Fig. 3 and 4.

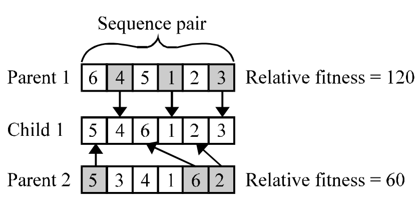

Fig. 3: Crossover operation on the first part SP = (Γ_+, Γ_-)

Mutation: The mutation operator is a mechanism that used to divert the GA search with a probability known as mutation probability (p_m). For first and second sequence of the first part of the chromosome the mutation operator involves a random selection and swapping of two integers. For the second third and forth part, the mutation operator involves randomly altering one symbol to another. For the last part, the mutation operation involves replacing a randomly chosen byte with a new value generated at random with range of [0, 255]. An example of the three types of mutation operators is shown in Fig. 5.

Control parameters: The control parameter values for genetic algorithm was determined based on trial experiments which produces satisfactory output are summarized as below:

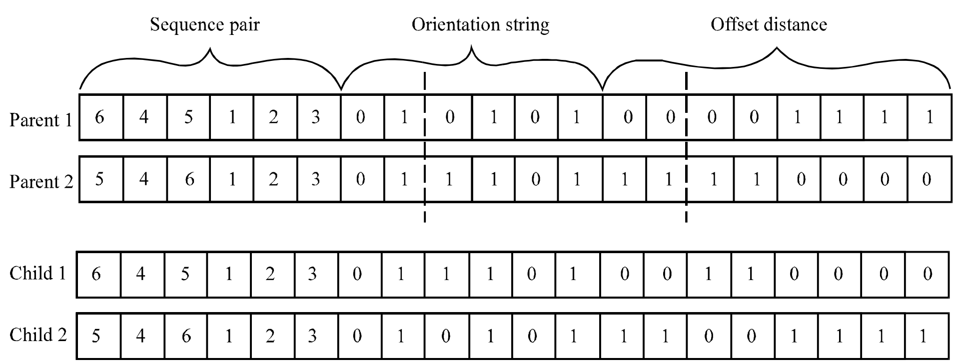

Fig. 4: Crossover operation on the second and fifth part

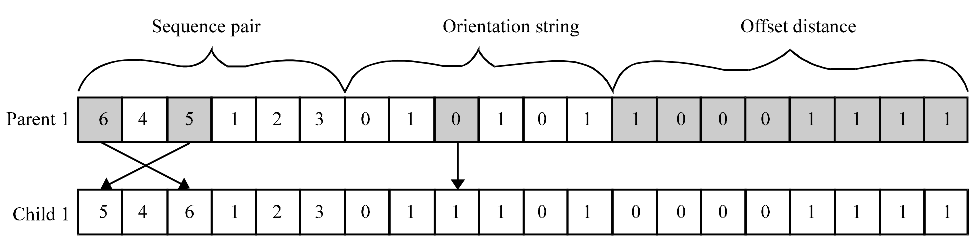

Fig. 5: Mutation operation on the first, second and fifth part of the chromosome

- Population size (P_s) = 20
- Cross over probability (p_c) = 0.8
- Mutation probability (p_m) = 0.25

Termination criterion: The search process is terminated if either of the following two conditions is satisfied. Firstly, the whole process of GA is terminated after 'r' number of consecutive iterations. After many trials it was found that 1000 is the best value for 'r'. Secondly, the search will also stop if the current best solution remains unchanged for's' subsequent generations. (After many trails, it was found that 10 is the best value for's').

RESULTS AND DISCUSSION

The proposed genetic algorithm based procedure was coded in MATLAB and implemented in Dual core processor with 2 GB RAM. Experiments were conducted using the bench mark problems (Welgama and Gibson, 1993; Wu and Appleton, 2002) found in the literature.

For each bench mark problem 10 different initial population set, each population set having 20 different initial solutions were generated at random. The experiment with each initial population was repeated 10 times and the best solution obtained for each of the bench mark problem is reported in Fig. 6 and Table 1. The average computational time taken by the algorithm to reach the optimal solution is given in Table 2.

Table 1: Total material handling cost values for the test problems

No. of cells	TMHC
6	496
7	200750
12	5837
20	992543

TMHC: Total material handling cost

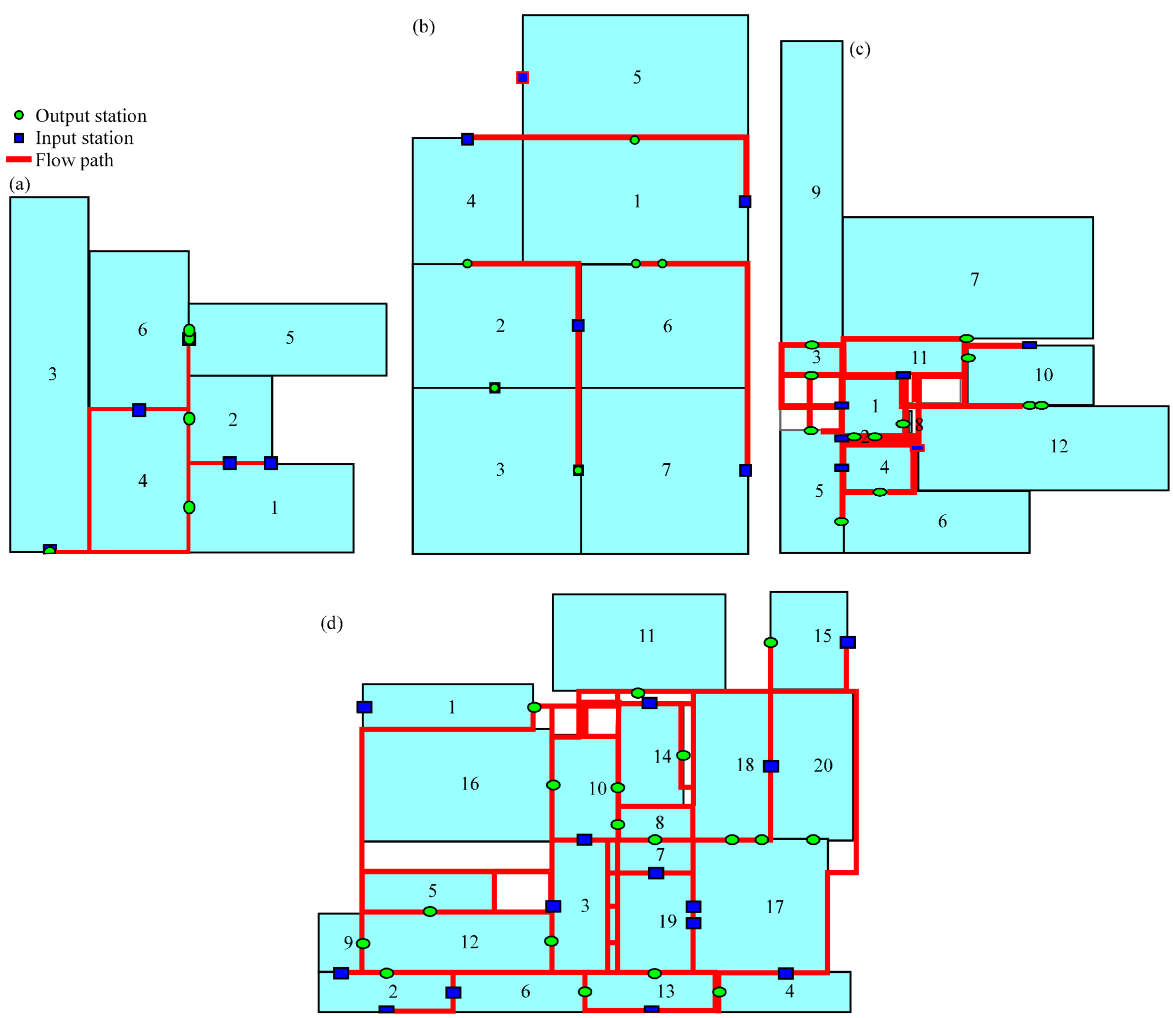

Fig. 6(a-d): The best layouts obtained by GA for the 4 test problems (a) 6, (b) 7, (c) 12 and (d) 20 cells

Table 2: Average computational time (sec)

No. of cells	6	7	12	20
Proposed GA	330	400	2400	14500

The proposed algorithm is consistent in producing solutions, out of each experiment which are closer to the best found solution.

CONCLUSION AND FUTURE WORK

To overcome the limitations out of sequential design procedure in the Layout design, integrated design of CSL (Inter-cell layout), I/O location determination and design of MHS was adopted. For optimization task, a genetic algorithm based procedure is proposed in this study. The proposed algorithm was tested with four different problems of different problem sizes to optimize TMHC. It is found that the proposed algorithm is able to produce satisfactory solution consistently within an acceptable computational time limit.

The outcome of this research leaves scope for further research towards designing more realistic layout by determining flow paths considering capacities of flow paths, the smoothness of material flows and the costs and area requirements for the construction of flow paths.

NOMENCLATURE

N	=	The total number of cells in the layout
W	=	The width of the floor space
H	=	The height of the floor space
i,j	=	Indices to denote cells
f_{ij}	=	The directed flow density from cell i to cell j
w_i	=	Width of cell i in the initial orientation
h_i	=	Height of cell i in the initial orientation
(x^I_i, y^I_i)	=	Spatial coordinates of the input station of cell i
(x_i^O, y_i^O)	=	Spatial coordinates of the output station of cell i
(x_i, y_i)	=	Spatial coordinates of the lower-left corner of cell i
(x'_i, y'_i)	=	Spatial coordinates of the upper-right corner of cell i
l_{ij}	=	Equals 1 if cell i is placed to the left of cell j; (that is $x'_i \le x_j$) and 0 otherwise
b_{ij}	=	Equals 1 if cell i is placed below cell j ; (that is $y'_i \le y_j$) and 0 otherwise
d_{ij}	=	Shortest contour distance from the output station of cell i to the input station of cell j
u_i,v_i	=	The orientation of cell i
P_i,Q_i	=	Location selection (input station) among four candidate points for cell i
R_i,S_i	=	Location selection (output station) among four candidate points for cell i:

$$(u_i, v_i) = \begin{cases} (0,0) \text{ original orientation} \\ (1,0) \text{ rotated } 90° \text{ clockwise from its original orientation} \\ (0,1) \text{ rotated } 180° \text{ clockwise from its original orientation} \\ (1,1) \text{ rotated } 270° \text{ clockwise from its original orientation} \end{cases}$$

$$(P_i, Q_i) \text{ and } (R_i, S_i) = \begin{cases} (0,0) \text{ candidate point 1 is selected} \\ (1,0) \text{ candidate point 2 is selected} \\ (0,1) \text{ candidate point 3 is selected} \\ (1,1) \text{ candidate point 4 is selected} \end{cases}$$

c_{ij}	=	The cost of travel of unit material for unit distance between cell i and j, $c_{ij} = 1\ \forall i,j$

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