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Layout design for efficient material flow path

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Abstract

Traditionally the design of physical layout of the manufacturing system (Inter-cell layout) 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 Inter -Cell Layout and 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 simultaneously optimize two contradicting objectives viz. 1. Total material handling cost (TMHC) 2.Total corner score (TCS). 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.

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Keywords: Integrated Layout Design; Genetic Algorithm,; Bi-criteria optimization, Total corner score.

1. 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 [1]. In the recent years researchers have focused on concurrent design of both *CSL* and *MHS* design by adopting

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integrated approach [2-5]. Hassan et al [6] reported the two differences between traditional block layout problem and CSL design in cellular manufacturing are specific cell shapes and predefined I/O stations of the cells. In this work an attempt has been made to develop a methodology to solve a bi-criteria optimization problem in an integrated layout design. The proposed algorithm is experimented with using a wide range of problem instances and found consistent in producing satisfactory solutions within a reasonable period of computational time.

2. 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 unique dimension. Given the width and height of the individual cell (determined by size and shape of the facilities), the predefined input and output stations located at the boundary of the cell, 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, and to decide the shortest aisle distance between the cells (along the department perimeter) with the objective of minimizing the total material handling cost (TMHC) and total corner score (TCS).

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), (x_i^O, y_i^O) spatial coordinates of the input and output station of cell i

(x_i, y_i), (x_i', y_i') spatial coordinates of the lower-left corner and 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

$$(u_i, v_i) = \begin{cases} (0,0) & \text{cell } i \text{ in its original orientation} \\ (1,0) & \text{cell } i \text{ is rotated } 90^{\circ} \text{ clockwise from its original orientation} \\ (0,1) & \text{cell } i \text{ is rotated } 180^{\circ} \text{ clockwise from its original orientation} \\ (1,1) & \text{cell } i \text{ is rotated } 270^{\circ} \text{ clockwise from its original orientation} \end{cases}$$

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

W1 weightage for total material handling cost (TMHC)

W2 weightage for total corner score (TCS), (W_2=1- W_1)

t_{ij} total number of corners (bends) exists between input station of cell i output station of cell j

Y_{ij} equals 1 if $f_{ij} \neq 0$ and 0 otherwise

The mathematical model for the integrated layout design problem is formulated based on the model represented in [4] and shown below:

$$\text{Minimize} \quad COF = \sum_{i=1}^{N} \sum_{j=1}^{N} (W_1 c_{ij} f_{ij} d_{ij} + W_2 t_{ij} d_{ij} Y_{ij}) + P \tag{1}$$

Where $P = \alpha(P_w + P_h)$ is a penalty term the guarantee that the layout solution satisfies the following floor boundary condition.

$x_i' \le w \ \forall i, \ y_i' \le H \ \forall i$

$P_w = max\{0, \max_i\{x_i'\} - W\}, \quad P_h = max\{0, \max_i\{y_i'\} - H\}$

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

Subject to:

$$x_i' = x_i + (1-u_i)w_i + u_i h_i \qquad \forall i \tag{2}$$

$$y_i' = y_i + (1-u_i)h_i + u_i w_i \qquad \forall i \tag{3}$$

$$x_i^{I(O)} = x_i + (1-u_i)(1-v_i)I(O_i^x) + I(O_i^y)u_i(1-v_i) + (w_i - I(O_i^x))(1-u_i)v_i + (h_i - I(O_i^y))u_i v_i \qquad \forall i \tag{4}$$

$$y_i^{I(O)} = y_i + (1-u_i)(1-v_i)I(O_i^y) + (w_i - I(O_i^x))u_i(1-v_i) + (h_i - I(O_i^y))(1-u_i)v_i + I(O_i^x)u_i v_i \qquad \forall i \tag{5}$$

$$l_{ij} + l_{ji} + b_{ij} + b_{ji} \ge 1 \qquad \forall i \tag{6}$$

$$x_i' \le l_{ij} x_j + W(1-l_{ij}) \qquad \forall i < j \tag{7}$$

$$y_i' \le b_{ij} y_j + H(1-b_{ij}) \qquad \forall i < j \tag{8}$$

$$x_i', y_i', x_i^{I(O)}, y_i^{I(O)} \ge 0 \qquad \forall i \tag{9}$$

$$u_i, v_i \in \{0,1\} \qquad \forall i \tag{10}$$

$$l_{ij}, b_{ij} \in \{0,1\} \qquad \forall i,j \tag{11}$$

$$Y_{ij} \in \{0,1\} \qquad \forall i,j, \tag{12}$$

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), (7) and (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) (10) (11) and (12) specify the bounds for each variable. In any facility layout design problem while it is imperative to minimize the total material handling cost which is directly proportional to the distance between the cells, often it is also essential to lay the flow path with minimum number of bends to facilitate smooth material transport. For this purpose a novel criteria TCS is being introduced and is being combined with the classical objective TMHC to make weighted single combined objective function (COF) in equation (1). In equation (1) the term (1) $W_1 c_{ij} f_{ij} d_{ij}$ represents the total material handling cost between the cell *i* to *j* which are separated by a distance of d_{ij} involving the flow intensity of f_{ij} at a cost of c_{ij}. (2) $W_2 t_{ji} d_{ij} Y_{ij}$ represents the total corner score between input station of cell i to output station of cell j which are separated by a distance of d_{ij} involving the total number of corners t_{ij}.

3. Proposed methodology

In this work, a simple GA was proposed to obtain the best feasible solution which minimizes simultaneously the TMHC and distance weighted TCS.

3.1. Solution representation

In a GA approach feasible solutions to the problem are encoded into a string of decision choices that resemble chromosomes. The chromosome that represents a feasible solution is shown in Fig.3.

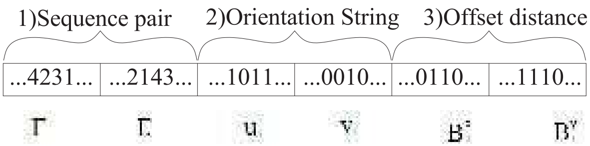

Fig. 3. Chromosome Structure

The chromosome string consists of three 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, 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: $\Delta x_i = (B_i^x/255) * \Delta X$ and $\Delta y_i = (B_i^y/255) * \Delta Y$. Where ΔX and ΔY are two preset constants and are problem dependant. In this study, they are set such that $\Delta X = \Delta Y = min\{ \min_i\{w_i\}, \min_i\{h_i\}\}$

3.1.1 Sequence pair representation

A cell system layout (CSL) can be represented by a unique sequence pair [7] 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. 4 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.

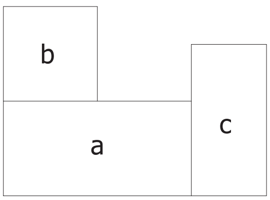

Fig. 4. CSL for SP = (*bac*; *abc*).

3.2 Fitness evaluation

The decoding of a chromosome and finding the objective function value for a feasible solution is done in four steps.

Step 1: Using first and second part of the chromosome, and the sequence pair evaluation algorithm Algorthim1 found in the literature [8] the spatial coordinates of the lowest left corner of each cell in a *CSL* is computed.

Step 2: The spatial coordinates of the I/O station [4] is determined.

Step 3: Then the grid graph [4] is constructed and then through repeated applications of Dijkstra's algorithm [9] 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 combined objective function (COF) value using equation (1).

3.3 GA operators

3.3.1. Selection

The selection module is constructed on the basis of Roulette wheel [10] 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.

3.3.2. 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 [11] 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 the last two parts of a chromosome, a heterosexual one-point crossover [12] was adopted. An example of this crossover operator is shown in Fig. 5 and Fig. 6.

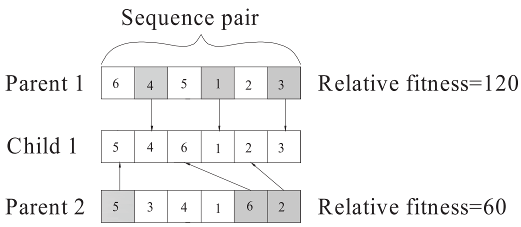

Fig. 5. Crossover operation on the first part $SP = (\Gamma_+, \Gamma_-)$

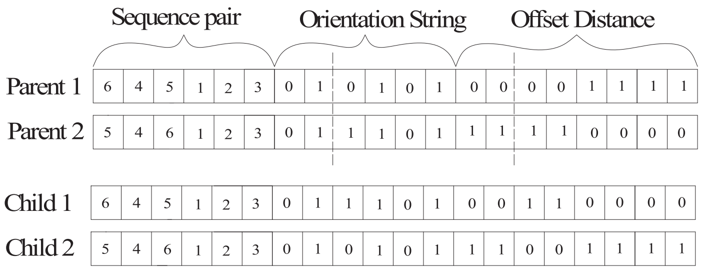

Fig. 6. Crossover operation on the second and third part

3.3.3. 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 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. 7.

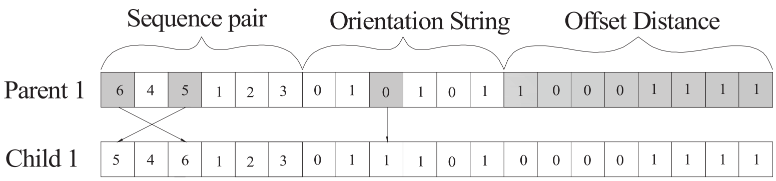

Fig. 7. Mutation operation on the first, second and third part of the chromosome

3.3.4. Control parameters

The control parameter values for GA based was determined based on trail experiments which produces satisfactory output are summarized as below:
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')

4. Results and discussion

The proposed genetic algorithm based procedure was coded in MATLAB and implemented in Dual core processor with 2GB RAM. Experiments were conducted using the bench mark problems [3], [13] and [14] 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 8 and Table 1. The average computational time taken by the algorithm to reach the optimal solution is given in Table 2.

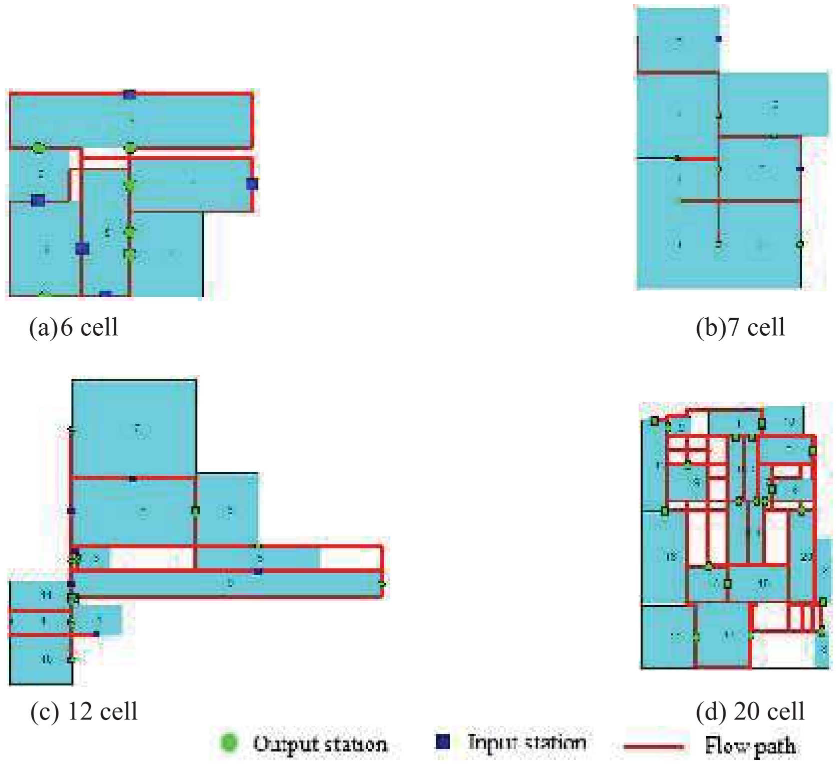

Fig. 8. The best layouts obtained by GA for the 4 test problems. a–d. W_1=0.5

Table 1. Bi-criteria values for the optimal solutions obtained

No of cells	W_1	W_2	OF_1	OF_2	Normalized OF_1	Normalized OF_2	COF
6	0.5	0.5	752.50	752.50	0.63	0.68	0.65
7	0.5	0.5	450500.00	370000.00	0.94	0.24	0.64
12	0.5	0.5	19063.50	8567.50	0.95	0.79	0.87
20	0.5	0.5	2130859.43	1437145.43	0.71	0.47	0.59

Objective function 1 (OF_1) – TMHC, Objective function 2 (OF_2) – TCS

Table 2. Average Computational time (s)

No of cells	6	7	12	20
Proposed GA	415	530	7000	17500

5. Conclusions and scope for future research.

To overcome the limitations out of sequential design procedure in the Layout design, integrated design of *CSL* and MHS was adopted. Again, to simultaneously optimize two different objective of the layout design problem a Genetic Algorithm based procedure is proposed in this work. The proposed algorithm was tested with four different problems of different problem sizes to concurrently optimize two objectives namely 1. Total material handling cost (TMHC) 2. Distance weighted total corner score (TCS). 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 employing a local search mechanism to further reduce the computational time. To provide wide range of alterative solutions to the implementers, a GA based multi objective evolutionary algorithm can also be developed to produce a pareto optimal front.

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