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A GENETIC ALGORITHM APPROACH TO DESIGNING AND MODELLING OF A MULTI-FUNCTIONAL FRACTAL MANUFACTURING LAYOUT

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ABSTRACT

A dynamic and optimal shop floor design, modelling and implementation is key to achieving successful Fractal Manufacturing System (FrMS). To build adaptive and fault-tolerant fractal layout, attention is paid to issues of shop floor planning, function layout, determination of capacity level, cell composition planning and flow distances of products. A full fledged FrMS. layout is multi-functional and is capable of producing a variety of products with minimal reconfiguration. This paper is part and a progression of an on-going project whereby Genetic Algorithm (GA) is adopted to design and model a flexible and multi-functional FrMS floor layout. GA is used in the project for modeling and simulation. The design implementation is done using MATLAB. The result is a fault tolerant configuration that self-regulates and adapts to unpredictable changes in the manufacturing environment arising from lead time reduction pressure, inventories, product customization and other challenges of a dynamic and volatile operational environment.

Keywords: fractal manufacturing layout, production planning, genetic algorithm.

1 INTRODUCTION

A dynamic and optimal shop floor design, modelling and implementation is key to achieving a successful FrMS. A full fledged FrMS. layout is conceptually capable of producing a variety of products with minimal reconfiguration. The conceptual fractal shop floor builds up from individual cells called fractals and is capable of producing a variety of products (Venkatadri *et al*. 1997; Montreuil *et al.*, 1999). The fractal layout is an extension of the cellular layout (Askin *et al*. 1999) and in fact, each fractal cell is a multi-functional mini shop (Venkatadri *et al*., 1997) since it could produce most of the product types routed to it and have layout specification that produce varied products. A design and simulation of the model of shop floor layout for FrMS is presented in this paper paying attention to determination of capacity level and cell composition using GA approach. The procedure is based on an iterative algorithm, implemented using MATLAB and used to calculate material travelling distances for each fractal cell and this continuously optimizes the layout, flow assignment and improves the overall performance of these parameters to create maximum space utilization. The rest of the paper is as follows; section two is on FrMS layout, section three presented FrMS layout design. Section four implemented the GA approach, while section five discusses output results and the paper is finally concluded in section six.

2 FRACTAL MANUFACTURING LAYOUT

The fractal workstation layout is created to minimize the capacity requirements and material travelling distances (Saad and Lassila 2004). The layout design concerns the arrangement of physical production resources within the production facility (Chase and Aquilano 1992) and the planning of which involves the determination and allocation of the available space to a given number of resources (Azadivar and Wang 2000) and emphasizes minimization of flow distances in order to improve product flow and general layout performance (Montreuil *et al.*, 1999). This involves various steps; capacity planning, fractal cell creation, flow assignment and cell/ global layout (Venkatadri *et al.*1997). These significantly affect shop floor control, equipment utilization, materials handling, materials management, and worker productivity (Co and Araar 1988). The manner and nature of the flow of materials through the facility is of crucial importance (Wild 1993).

2.1 Multi-functionality of fractal cell

The fractal cell is a set of neighboring workstations and is the basic unit in the fractal layout system (Saad and Lassila 2004; Venkatadri *et al.* 1997 & Montreuil *et al.* 1999). It should generate the manufacturing procedures and routes, production scheduling, material requirement planning etc. (Prasada, K.V., 2005). All fractal cells have roughly the same composition of machines and are capable of processing most of the products routed to them. This capability of producing a variety of products with minimal reconfiguration is termed multi-functionality and directly impacts on the flexibility of the system. The most important objectives of the fractal layout are how to minimize the movement and handling of materials, maximize the capacity utilization (Wild 1993) and ensure a smooth work flow (Chase and Aquilano 1992). Shop floor control manages the work in process (Figure 1) and production orders through the various workstations (Prasada, K.V., 2005).

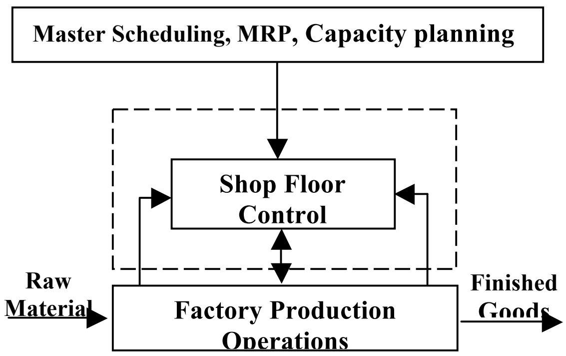


Figure 1: Relationship of Shop floor control in Production System (Prasada, K.V., 2005).

3 THE PROPOSED FRACTAL MANUFACTURING LAYOUT DESIGN

As a guide, the initial fractal manufacturing layout adopted for this study is the cellular manufacturing systems configuration proposed by (Co and Araar 1988) (Figure 2). This layout is re-designed and reconfigured from its initial cellular manufacturing layout using the GA optimization technique. Limitations of the cellular manufacturing layout include inflexibility due to a fixed set of part families and limited allowance for inter-cell flows. It also contains different types of machines which increases the product inter-cell and intra-cell travelling distances. This design is modified and illustrates with 15 distinct product types and 10 types of machine in the initial cellular layout. A total of 64 workstations are located in the factory. But, each group of cell contains uncertain number of machines. In this study, the GA approach lets us represent the entire group layout proposed by (Co and Araar 1988), (Figure 2) as chromosomes. MATLAB made the representation of the machines in each cell easier. Cell1is represented as (1 5 2 6; 7 4 3 8; 9 10 3 5; 2 10 8 6; 1 5 9 10) in MATLAB codes. Cell4 is coded as (3 9 2 8; NaN NaN NaN 5) (where NaN means Not-a-Number in computing). Cell1 and

Cell4 are combined using crossover operations. Cell1 is re-generated and it becomes one of the output cells for fractal manufacturing layout.

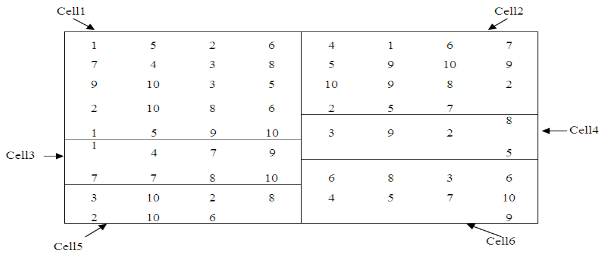


Figure 2: Modified group layout from (Co and Araar 1988)

All fractal cells are similar and contain roughly the same composition of machines. Similarity of fractal cells in terms of machine types and quantities enable high efficiency in controlling shop floor, high operational flexibility and high flexibility for factory expansion. The design of fractal layout (Figure 3) contains three cells. This choice leads to a cell population of 10 workstations, which is within tractable standards of 5 to 15 machines in each fractal cell. It is not necessary to limit the number of workstations to 30 machines in this case (Venkatadri *et al.*, 1997). But, by adding few more workstations congestion could be alleviated and flow efficiency could further be improved.

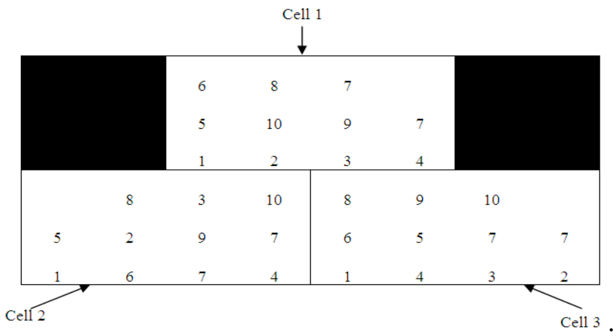


Figure 3: Fractal Manufacturing layout (Co and Araar 1988)

4 IMPLEMENTING THE GENETIC ALGORITHM APPROACH

An iterative algorithm is implemented to optimize the layout and flow assignment. The layout of each cell is refined while the replicates are re-applied until the heuristic procedures could not find a better solution. The cells are continually iterated to obtain the optimal flow assignment and hence achieve the optimum fractal layout (Montreuil *et al.*, 1999). The GA procedures - selection, crossover, row inverting mutation, column inverting mutation, and deleting mutation are embedded in the iterative procedure in order to generate the optimal material travelling distances. Hence the desired workstation layout that minimizes the material travelling distances and capacity requirements for product demand and mix is created. Each optimal fractal cell is selected based on the flow distance score. Thus, optimum fractal manufacturing layout is created by combining the three optimal fractal cells. The illustrations of the GA steps are presented, showing the first iteration of the fractal cell 1. Initial cellular layout is assumed to contain 6 cells. Fractal cell1 is generated by combining cell 1 and cell 4 by crossover operation. Cell 1 is shown as parent1 and cell 4 is illustrated as parent2 in MATLAB program codes. Chromosomes for each Parent are represented by the various kinds of genes. The genes are represented by the number 1 to 10 that signify that Machine1 to Machine10 are used. Parent1 is represented as (1 5 2 6; 7 4 3 8; 9 10 3 5; 2 10 8 6; 1 5 9 10), illustrated in 5 rows and 4 columns. Parent2, contains 2 rows and 4 columns as (3 9 2 8; NaN NaN NaN 5). The chromosome for each parent is represented in rows. This means that the chromosomes for Parent1 are (1 5 2 6), (7 4 3 8), (9 10 3 5) and so on. One of the chromosomes from Parent1 is chosen randomly. For instance, the first row chromosome for Parent1 has been selected for the crossover function. On the other hand, the 1st row chromosome for Parent2 also is selected to be combined with the chromosome of Parent1 as shown in (Figure 4). The continuous selection of the chromosomes for Parent1 and Parent2 generated 10 different Offspring after the crossover operation (Figure 4). Two Off-springs are generated from each iteration of the crossover. The Offspring1 that is created from selection and crossover with 5 chromosomes are selected for the upcoming mutation. Offspring2 is not been used because there are only 3 chromosome lesser than in Offspring1. Inverting mutation takes place after the crossover. The Offspring that is generated in the previous crossover is used as the Parent again in this inverting mutation operation. Initially, a cutting point is randomly introduced anywhere along the last row of the Parent. The cutting point indicates the row of the chromosomes for the inverting mutation. The last row of the chromosome is being mutated to the initial row based on the programming code "circshift" - (mathscript function). For each offspring that is generated, three column inverting mutations takes place. For column inverting mutation, chromosome is represented column by column. The cutting point is set in the last column of the chromosome. The column-based chromosome is mutated and shifted from the last column to the first column.

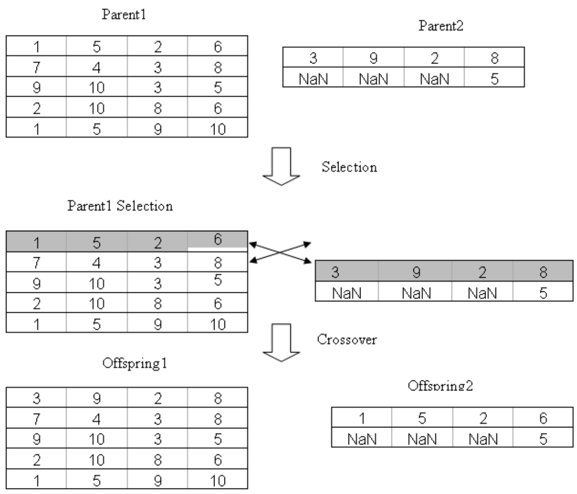
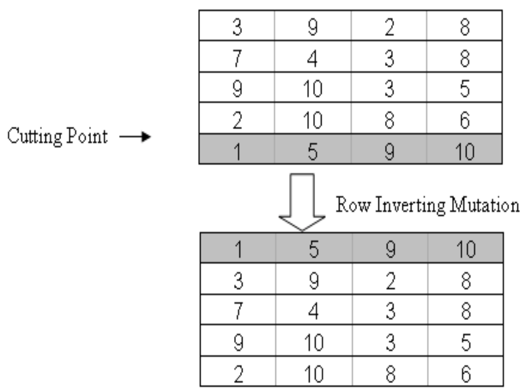


Figure 4: Selection and Crossover

After this, the Parent is replicated by shifting its chromosomes in columns as shown in (Figure 5). For each Parent that is obtained from the previous mutation step, the entire inverting mutation is expected to replicate 12 times.



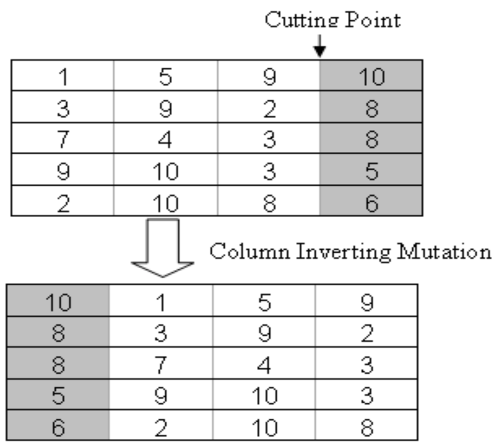


Figure 5: Row Inverting Mutation

Figure 6: Column Inverting Mutation

After inverting mutation (Figure 6), the Child is generated and transformed to be the Parent again for deleting mutation as shown in (Figure 7). On completion of the previous mutation, the process of deleting mutation is simplified by just deleting the last two rows of the five chromosomes in the Child.

10	1	5	9
8	3	9	2
8	7	4	3
5	9	10	3
6	2	10	8

Deleting Mutation

10	1	5	9
8	3	9	2
8	7	4	3

Figure 7: Deleting Mutation

10	1	5	9
8	3	9	2
8	7	4	3

Replacement

10	1	5	9
8	3	6	2
NaN	7	4	NaN

Figure 8: Replacement

Replacement is the last step in the process of generating fractal cell layout as shown in (Figure 8). Each fractal cell requires 10 machines where no duplicated machines or missing machines are allowed. The program searches the missing machines which is machine6. Thus, machine6 replaces one of the duplicated machines. The fractal cell layout that is generated after Replacement can be represented as (10 1 5 9; 8 3 6 2; NaN 7 4 NaN). Materials are moved into the cell through Pick-up Points and moved out from the cell through Delivery Points as shown in (Figure 9). The Pick-up Point is at (1, 1) while the delivery Point is at (3, 4). Before the materials are processed in machine1, they have to be carried into the fractal cell through the Pick-up Point. After processing within the fractal cells, the final product1 gets delivered to the shipping department through Delivery Point as shown in (Figure 9).

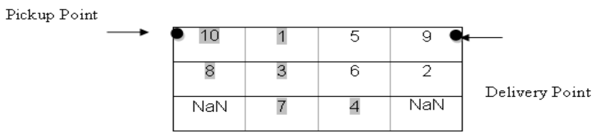


Figure 9: Material Routing sequence for Product1

Then the flow distance score is calculated based on the mathematical solution in MATLAB which is represented as:

Distance = abs(buffer1(1)-buffer2(1))+abs(buffer1(2)-buffer2(2)) ……………………………….(1)

abs is abbreviation of absolute. The absolute value allows the distance to the left (negative value) and distance to the right (positive value) to be counted into the total distance. Buffer1 and buffer2 are the matrices of data that are being stored in temporary memory.

5 OUTPUT RESULTS AND DISCUSSIONS

The computational result of product travelling distances within the fractal cells indicates the flow scores of fractal layout. Flow score is computed and represented as the product travelling distances.
The GA search for an optimal solution yielded results from 100 iterations and the output is converted into the final fractal cell layout representing the fractal manufacturing layout. The material travelling distances for each of the three fractal cells are; Flow distance score for Cell 1 = 205; Flow distance score for Cell 2 = 217; Flow distance score for Cell 3 = 197. Overall flow distance score for the final fractal manufacturing layout through the proposed GA = 619 and this is shown in (Figure 10). Comparatively, the fractal layout according to (Venkatadri *et al.*1997) has machine requirements similar to our final layout requirements with the following flow distances; Flow distance score for Cell 1 = 251; Flow distance score for Cell 2 = 252; Flow distance score for Cell 3 = 257. Overall flow distance score for Final Fractal Layout according to (Venkatadri *et al.*1997) is = 760 and that is shown in (Figure 11). This shows that the flow distance score obtained from the proposed GA approach

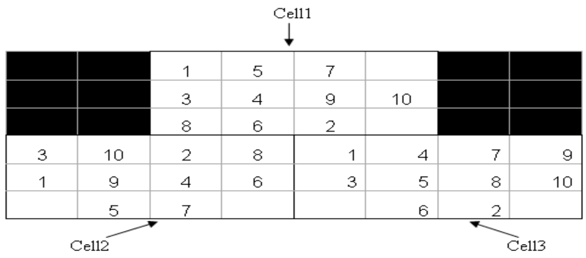


Figure 10: Final Fractal Manufacturing Layout A

is lesser at 619 than that of (Venkatadri *et al.*1997).

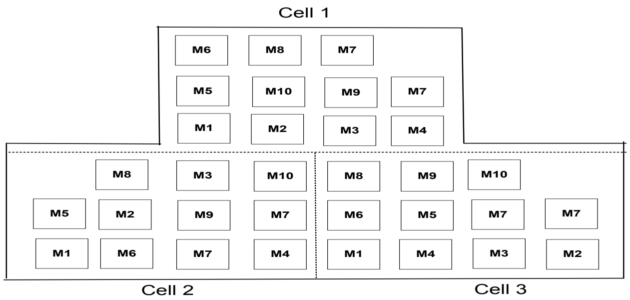


Figure 11: Fractal cell layout according to (Venkatadri et al.1997)

6 CONCLUSION

The GA approach was used in the design of the FrMS shop floor layout. It was used to search for optimal fractal cell layout for efficient and effective material/ product movements within the shop floor. The decision of how to distribute/assign products to cells as evenly as possible to aid responsiveness to uncertainties and easy control of resources was important in the design, implementation and final outcome of the experimentation. MATLAB managed the scenario quite well and handled the mathematical formulations, swapping and deleting matrices etc. quite efficiently. Overall, the computational results indicated that unrestricted product flows offer the best flow scores in a fractal layout.

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