Bazargan-Lari, Massoud and Nahavandi, Saeid 2001, The impact of cell formation on layout designs in cellular manufacturing, *Intelligent automation and soft computing*, vol. 7, no. 1, pp. 13-22.

Intelligent Automation and Soft Computing, Vol. 7, No. 1, pp. 13-22, 2001

THE IMPACT OF CELL FORMATION ON LAYOUT DESIGNS IN CELLULAR MANUFACTURING

MASSOUD BAZARGAN-LARI
Business Administration Department
Embry-Riddle Aeronautical University, Florida

AND

SAEID NAHAVANDI
School of Engineering and Technology
Deakin University, Victoria, Australia

ABSTRACT—This paper provides a procedure to address all three phases of the design for cellular manufacturing namely parts/machines grouping, intra-cell and inter-cell layout designs concurrently. It provides a platform to investigate the impact of the cell formation method on intra-cell and inter-cell layout designs and vice versa by generating multiple efficient layout designs for different cell partitioning strategies. This approach enables the decision maker to have wider choices with regard to the different number of cells and to assess various criteria such as travelling cost, duplication of machines, space requirement against each alternative. The performance of the model is demonstrated by applying it to an example selected from literature.

Key Words: Cellular Manufacturing, Intra-cell Layout, Inter-cell Layout, Multi Criteria, Simulated Annealing, Goal Programming.

1. INTRODUCTION

Cellular Manufacturing (CM), an application of Group Technology (GT), utilises the concept of divide and conquer and involves the grouping of machines, processes and people into cells responsible for manufacturing or assembly of similar parts or products [1].

Different and independent surveys conclude that significant improvements can be achieved as a result of implementing CM in areas such as lead times, set up times, work in process, quality, machine utilisation and employee job satisfaction (see for example Wemmerlov and Johnson [2]).

A recent survey conducted on the impact of CM on Australian manufacturing companies with over $10 million annual turnover showed that about 209 companies (accounting for 52% of the companies surveyed) are already using or are in the process of implementing CM, with a further 28% indicating their future plans to introduce CM to some part of their operations. Of the companies already using CM, more than 70% reported improvements in one or more aspects of lead times, lot sizes, labour productivity, set-up times, on-time delivery, labour flexibility and quality. The main attraction of CM is that it normally requires no additional capital investment or workers [1].

The design for cellular manufacturing involves three stages [3], (i) grouping of parts and production equipment into cells, (ii) allocation of the machine cells to areas within the shop-floor (inter-cell or facility layout), and (iii) layout of the machines within each cell (intra-cell or machine layout). The realisation of benefits expected from Cellular Manufacturing (CM) largely depends on how effectively the three phases of the design have been performed.

A common strategy adopted by many researchers in addressing these sub-problems, is to address each phase separately and sequentially without evaluating the impact of each phase on the previous phase(s). This limitation results in generating solutions which may be efficient to one particular phase but does not necessarily offer a good solution to the overall CM design [4]. The existing layout algorithms for CM often fall short of addressing the practical issues normally present in a real-world problem. These limitations include lack of consideration for issues such as cells/machines dimensions, closeness relationships, aisles, location restriction-preferences and most important of all the possibility of generating multiple layout designs.

This paper presents an integrated approach to the three phases of the design of cellular manufacturing. In this approach, the decision maker is provided with multiple efficient alternative solutions according to different cell-partition strategies. It offers the flexibility to assess each alternative against tangible and intangible benefits and criteria. The capability of the model is demonstrated by applying it to an example and an industrial CM design.

This research is the extension of research work on the integration of inter and intra-cell layout designs [5, 6, 7]. In these publications, it is shown how the two sub-problems pertaining to the layout design of CM are related and the need for an integrated approach to address both the intra-cell and inter-cell is demonstrated.

Section 2 presents a brief overview of the integrated model on intra-cell and inter-cell layout designs presented in [5, 6, 7]. Section 3 briefly describes the methodology to generate parts/machine grouping together with the intra and inter-cell layout designs. In section 4 an example is introduced and solved using the model. Section 5 concludes this paper.

2. INTRA-CELL AND INTER-CELL LAYOUT DESIGNS

The mathematical programming model adopts a continuous plane approach. It first introduces a general machine layout problem [5, 7] by considering various constraints to handle issues such as unequal size and irregular shape machines or cells, aisles, minimum or maximum desired space between any two machines, imposing location restrictions or preferences for machines and orientations. A combination of non-linear goal programming in the class of multi-objective methods and simulated annealing in the class of random search methods is used to solve the mathematical model.

This machine layout methodology is next utilised and modified to address the intra-cell layout designs in a cellular manufacturing environment [6]. In generating the intra-cell layout designs, three distinct sets of objectives have been considered. The first set concerns the feasibility of the solution, such as non-overlapping condition.. The second set of objectives is to minimise the area of the cell. In this model the boundaries and shapes of the cells are not fixed and accordingly the algorithm has the flexibility to determine the 'appropriate' cell boundaries. The third objective is to minimise the travelling cost.

The algorithm first seeks solutions by assigning feasibility, minimisation of the area of the cell and intra-cell travelling cost to priority levels 1, 2 and 3 respectively (based on the goal programming pre-emptive characteristics). The solution thus generated has the lowest area and highest intra-cell cost. Starting from this solution, the algorithm is next run again only reversing the priority levels of the two objectives, area and travelling cost. In this case the final solution will have the lowest travelling cost and highest cell-area. During this transition of going from one extreme solution having the smallest area and the largest cost to the other with the smallest cost and largest area, a large number of solutions are generated of which many are efficient (non-dominated) points. The number of efficient solutions generated is normally large. A filtering process has been used to deal with such information overload.

The method next seeks to generate the alternative inter-cell layout designs [6] by considering all possible combinations for efficient intra-cell designs, using similar process described for intra-cell layout designs.

The main capability of this model is that it avoids generating a single 'take it or leave it' solution and provides the decision maker with an array of non-dominated solutions. The rationale being that in an industrial layout planning there are many issues such as human factors, safety and employee satisfaction which are unqunatifiable. The presentation of these multiple non-dominated solutions enables the decision maker to assess each layout against such unquntifiable factors and select the most appropriate one.

3. CELL PARTITIONING MODEL

The main task of cell formation is to group the machines into cells to produce a number of part families [8]. Currently there exist a large number of efficient cell-partitioning algorithms in the literature [2, 9].

The main purpose here is not to introduce a new cell-formation model, but to demonstrate how the existing models can be modified and adopted in order to be integrated with intra and inter-cell layout designs presented in section 2 to overcome the limitation of sub-optimisation. The model used and modified (without loss of generality), is the cell-partitioning approach developed by Heragu and Kakuturi [9]. For description of the mathematical model and the proposed methodology, the interested reader is referred to [9].

This model utilises part routing, annual demand and batch sizes to perform the cell formation. The major distinction between the algorithm presented by Heragu and Kakuturi [9] and the proposed model in this paper is the approach taken to perform the cell partitioning. The objective of the former algorithm is to determine the number of cells and their corresponding parts and machines belonging to each cell so that the number of exceptional parts (the parts which require further processing outside their designated cell) is minimised. In this paper, however, it is assumed that the number of the cells is initially set to a minimum number of cells (for example two cells). Based on this parts/machine grouping a set of non-dominant solutions for intra and inter-cell layouts are generated. The number of cells is then incremented by one again arriving at a new solution for parts/machine grouping and layout designs. This process is continued until all the possibilities of number of cells are examined according to the user specification. By efficient intra and inter-cell layout designs we mean solutions which are non-dominant with respect to the aforementioned criteria namely travelling distances and areas for intra/inter-cells.

4. EXPERIMENTATION AND COMPUTATIONAL RESULTS

Many of the test data available in the literature pertaining to CM, consider only one phase of the design and thus do not normally provide the full information regarding all the three phases. In order to show the capability of the method in generating multiple cell design solutions, a problem is introduced and solved using the cell formation algorithm described in sections 2 and 3. Some of the information, however, is similar to the test data provided by Heragu and Kakuturi [9] and Souilah [10].

The problem concerns a manufacturing system consisting of 12 machines and 19 parts. Table I presents the machine dimensions and Table II shows the routing in the form of operation sequences for each part. For example part 1 requires two operations for which the first operation is performed on machine 12 and the second operation on machine 6. Table II also presents the demand per period (D) and transfer batch (B) for each part. In order to facilitate better material movement at least 1.5 m space should be placed between any two machines in any cell and between any two cells. It is also desired that the number of machines per cell should not be less than 3. This constraint, results in the number of cells to be at least 2 and at most 4.

Tables III, IV, and V present the solutions generated by the proposed hybrid method for the three sub-problems of cell formation, intra and inter-cell layout designs for different cell-partitioning strategies. In tables IV and V, area corresponds to the area of the smallest rectangle enclosing the facilities and cost represents the travelling distances. Different non-dominated solutions are generated for the intra and inter-cell layout designs according to the cell formation strategy. For example for the 2 cell-partitioning strategy, 3 efficient alternative intra-cell layout designs (a,b,c) are generated for cell 1 and similarly 3 alternatives for cell 2. Integrating these intra-cell layout designs, generates 2 efficient inter-cell alternatives. These two solutions are generated by including alternative b for cell 1 (1b) and alternative b for cell 2 (2b), or alternative c for both cells 1 and 2 (1c, 2c) as shown in Table V.

The physical layout for intra-cell and inter-cell layout designs are presented in Figures 1 to 12. These figures correspond to the alternatives shown in Tables IV and V.

Table I. Machine dimensions (mxm).

1	2	3	4	5	6	7	8	9	10	11	12
1.5×2	2×1	2.5×2.5	2×1.5	2.5×1	2×2	1.5×1.5	1×2	1.5×1.5	2×1	1.5×1.5	1×2

Table II. Part routing, demand per period (D) and transfer batch size(B) information.

Machine Type

		1	2	3	4	5	6	7	8	9	10	11	12	D	B
	1						2						1	20	5
	2	3								1		2		30	6
	3		2			3			4				1	20	5
	4			2	3						1			20	4
	5			3	2						1			50	10
P	**6**		3			1			2					30	6
A	**7**			2	1	3								40	10
R	**8**			3			1						2	20	10
T	**9**						2	3					1,4	10	2
	10			1	2			4			3			30	10
T	**11**				1,3						2			20	5
Y	**12**	4				2				3		1		10	5
P	**13**						1	2					3	60	20
E	**14**		2						1,3					20	5
	15	2								1		3		40	8
	16						2	1,3						50	5
	17	2	1						3	4				10	5
	18	3								2		1		20	4
	19			1	2									30	6

Table III. Solution for different cell-partitioning strategies.

Strategy	**Cells**	**machines assigned to**	**Parts Assigned to**
2-cell partition	cell - 1	1,2,5,8,9, 11	2,6,12,14,15,17,18
	cell - 2	3,4,6,7,10,12	1,4,5,8,9,10,11,13 16,19
	bottlenecks	5,12	3,7
	total inter-cellular movements = 7		
3-cell Partition	cell - 1	1,2,5,8,9, 11	2,6,12,14,15,17,18
	cell - 2	6,7,12	1,9,13,16
	cell - 3	3,4,10	3,7,8,10
	bottlenecks	5,12,3,7	3,7,8,10
	total inter-cellular movements = 10		
4-cell Partition	cell -1	1,9,11	2,15,18
	cell -2	2,5,8	6,14
	cell -3	6,7,12	1,9,13,16
	cell -4	3,4,10	5,11,19
	bottlenecks	5,12,3,7,1,8	3,7,8,10,12,17
	total inter-cellular movements= 19		

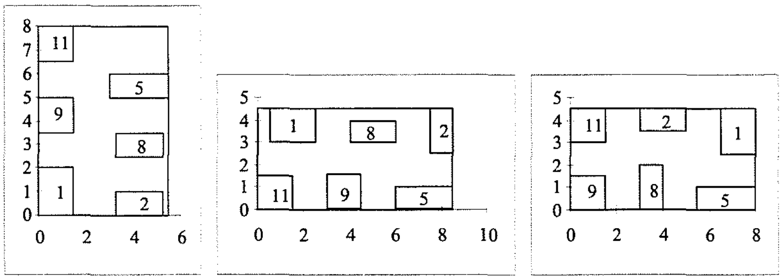
Table IV. Non-dominated intra-cell layout solution for different cell-partitioning strategies.

Strategy	**Cell**	**alt.**	**area (m^2)**	**cost (m)**
2-cell partition	1	a	44.0	255.0
		b	38.7	281.5
		c	36.0	369.7
	2	a	71.1	356.6
		b	60.7	376.2
		c	45.0	382.0
3-cell partition	1	a	44.0	255.0
		b	38.7	281.5
		c	36.0	369.7
	2	a	22.5	174.0
		b	15.0	179.0
	3	a	21.4	152.2
		b	20.0	192.0
4-cell partition	1	a	22.5	174.0
		b	15.0	179.0
	2	a	21.4	152.2
		b	20.0	192.0
	3	a	15	126.0
		b	12.0	131.5
	4	a	9.5	108.7
		b	15.0	75.0

Table V. Non-dominated inter-cell layout solutions for different cell-partitioning strategies.

Strategy	**alternatives.**	**area (m^2)**	**cost (m)**
2-cell partition	1b,2b	120.5	669.7
	1c,2c	92.5	763.7
3-cell partition	1a,2b,3a	107.9	622.8
	1a,2b,3b	104.0	662.5
4-cell partition	1a,2a,3b,4b	99.0	616.9
	1b,2b,3b,4b	95.0	655.3

2 cell-partitioning strategy

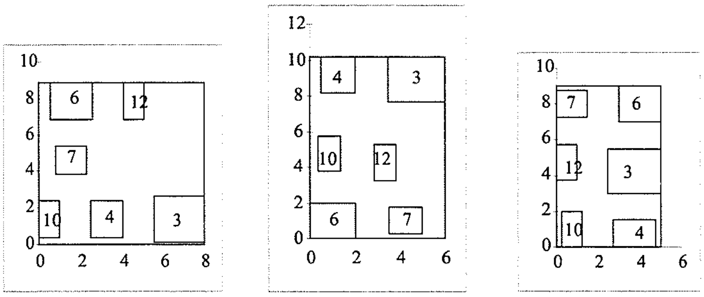


(a)
area=44.0 m^2
cost=255.0 m

(b)
area=38.7 m^2
cost=281.5 m

(c)
area=36.0 m^2
cost=369.74 m

Figure 1. Three efficient Intra-cell layout designs for cell 1.

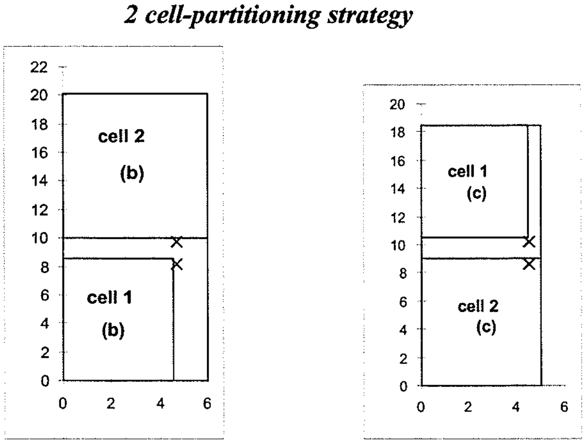


(a)
area=71.1 m^2
cost=356.6 m

(b)
area=60.7 m^2
cost=376.2 m

(c)
area=45.0 m^2
cost=382.0 m

Figure 2. Three efficient Intra-cell layout designs for cell 2.

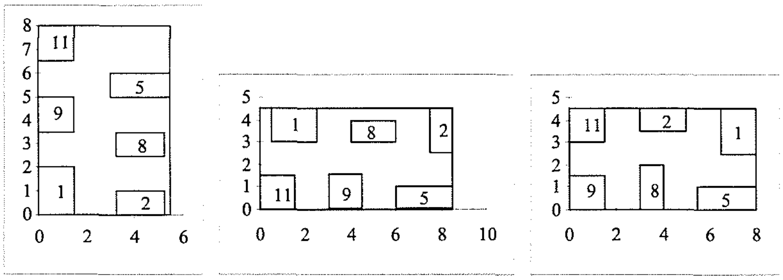


(1)
area=120.50 m^2
cost=669.72 m

(2)
area=92.50 m^2
cost=763.75 m

Figure 3. Two efficient Inter-cell layout designs for the 2 cell-partition with loading/unloading points (×).

3 cell-partitioning strategy



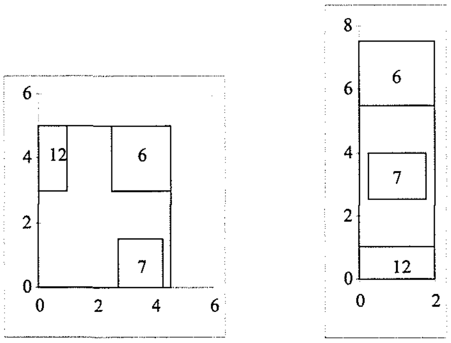
(a)
area=44.0 m^2
cost=255.0 m

(b)
area=38.7 m^2
cost=281.5 m

(c)
area=36.0 m^2
cost=369.74 m

Figure 4. Efficient Intra-cell layout designs for cell 1 (3 cell-partition).

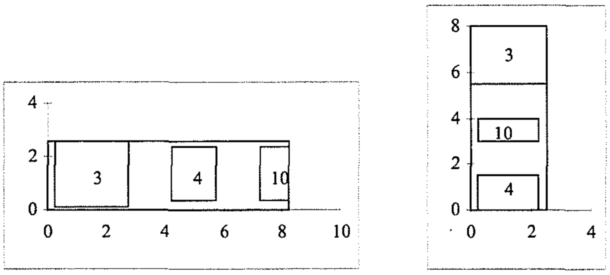
3 cell-partitioning strategy



(a)
area=22.5 m^2
cost=174.0 m

(b)
area=15.0 m^2
cost=179.0 m

Figure 5. Efficient Intra-cell layout designs for cell 2 (3 cell-partition).



(a)

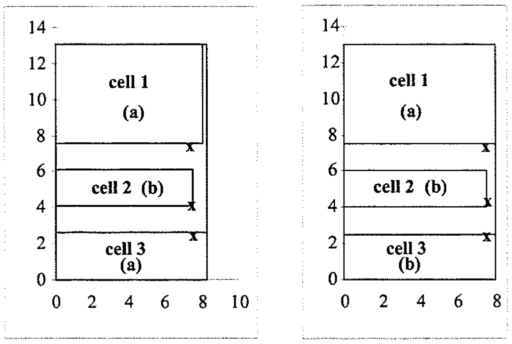
(b)

area=21.4 m^2
cost=152.2 m

area=20.0 m^2
cost=192.0 m

Figure 6. Efficient Intra-cell layout designs for cell 3 (3 cell-partition).

3 cell-partitioning strategy

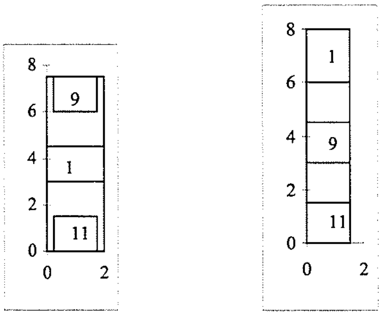


(1)
area=107.9 m^2
cost=622.8 m

(2)
area=104.0 m^2
cost=662.5

Figure 7. Efficient Inter-cell layout designs for the 3 cell-partition with loading/unloading points (x).

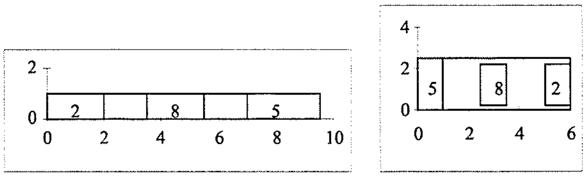
4 cell-partitioning strategy



(a)
area=15.0 m^2
cost=126.0 m

(b)
area=12.0 m^2
cost=131.5 m

Figure 8. Efficient Intra-cell layout designs for cell 1 (4 cell-partition).



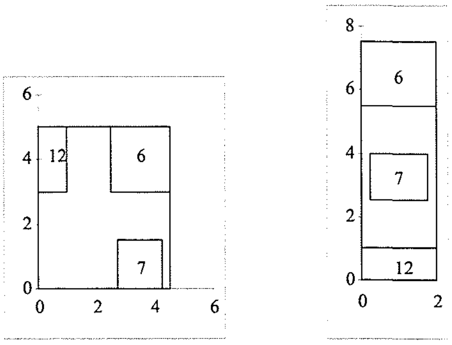
(a)

(b)

area=9.5 m^2
cost=108.7 m

area=15.0 m^2
cost=75.0 m

Figure 9. Efficient Intra-cell layout designs for cell 2 (4 cell-partition).

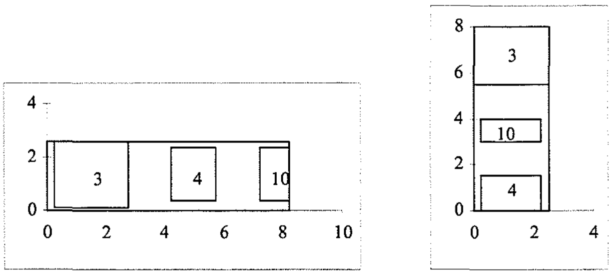


(a) *(b)*

area=22.5 m^2
cost=174.0 m

area=15.0 m^2
cost=179.0 m

Figure 10. Efficient Intra-cell layout designs for cell 3 (4 cell-partition)

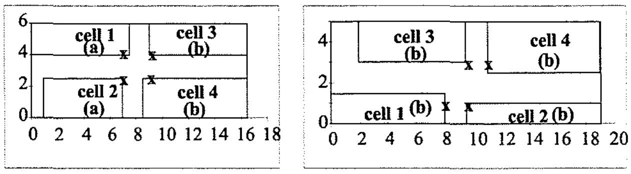


(a) *(b)*

area=21.4 m^2
cost=152.2 m

area=20.0 m^2
cost=192.0 m

Figure 11. Efficient Intra-cell layout designs for cell 4 (4 cell-partition).



(1) *(2)*

Alternative (*1*)
area=99.0 m^2
cost=616.9 m

Alternative (*2*)
area=95.0 m^2
cost=655.26

Figure 12. Efficient Inter-cell layout designs for the 4-cell partition.

As the Tables and Figures suggest, different cell-partition strategies result in different inter-cell and intra-cell layout designs and vice-versa. It should be noted that the existing cell formation algorithms (including [9]) will only produce the 2 cell-partition solution since it generates fewer inter-cellular movements than the other solutions. The integrated approach however provides the necessary guidelines to the management for assessing different tangible and intangible benefits against each alternative. The management may, for example, be interested in duplicating certain machines (based on the solutions provided), aiming at increasing the number of cells thus enjoying intangible benefits of CM, such as fewer number of parts per cell and easier production management.

5. CONCLUSION

This paper presented how the integrated approach for the layout designs can be extended to address all the three phases of the design of cellular manufacturing. It was shown how the existing cell-formation algorithms can be modified and used to generate different cell-partition solutions. This proposed integrated approach, provides the decision maker with multiple efficient alternative solutions according to different cell-partition strategies. It offers the flexibility to assess each alternative against tangible and intangible benefits and criteria. The capability of the proposed method was shown by applying it to an industrial CM design problem. The solutions generated proved to be not only feasible by addressing all the constraints expressed by the company but also provided a lower travelling cost and was prepared at a fraction of traditional planning time and cost.

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