DESIGN OF CELLULAR MANUFACTURING SYSTEM: A CASE STUDY

Shivprakash B. Barve[1], Prakash M. Khodke[2]
[1]Professor, Department of Mechanical Engineering, MAEER's MITCOE, Kothrud, Pune, Maharashtra, India,
[2]Principal, Government College of Engineering, Karad, Maharashtra, India.

Abstract
The purpose of this study is to develop an effective design of Cellular Manufacturing System (CMS) in dynamic production requirement with multiple objectives. Simulated annealing (SA) method is proposed optimization. The method is discussed and the model is implemented successfully in a manufacturing company with two period planning horizons. The algorithm developed in this study reduces intercell movement cost and intracell movement cost. An algorithm of CMS design minimizes total CMS cost and works in real life situation.
Index Terms: Cellular Manufacturing System, Simulated Annealing.

I. INTRODUCTION

Cellular Manufacturing System is a promising alternative manufacturing system to improve manufacturing efficiency. In CMS, machines are arranged in Machine Cells and parts are grouped in part families. Machines in the each machine cell are grouped such that, maximum operations of each part family are processed in the same machine cell.

Various machine cell and part family formation methods are available in the literature. Most popular computational methods for CMS are Fuzzy Set Theory [1, 2], Artificial Neural Network (ANN) [3], Genetic Algorithm (GA) [4,5] and Simulated Annealing (SA) [6-9].

Most of the current CMS design methods have been developed for the static condition with single period planning the horizon with an assumption that product mix and demand is constant for the entire period [10-11]. In actual practice product mix and demand fluctuates.
This paper presents the Simulated Annealing algorithm for a CMS in a dynamic production requirement with multiple objectives for minimizing production costs.

II. CMS DESIGN

The objective of CMS design is to reduce the total cost. The CMS Design includes four steps such as Initial Cell Formation, Generation of Initial Feasible Solution, Design of Cell Configuration and Elimination of Excessive Machines to Reduce Cost.

2.1 Initial Cell Formation

WLF method is used for initial cell formation [12]. Similar parts are grouped into part families and machines into machine cell simultaneously.

Work Load Fraction (WLF):

WLF of a machine 'M_i' in a cell 'C_j' is defined as the ratio of the within-cell work load on the machine 'M_i' as given in equation (1).

$$WLF = \frac{Within\ cell\ utilisatio\ n\ of\ \ machine\ \ M_i}{Total\ \ utilisatio\ n\ M_i} \cdots (1)$$

Cell Admission Factor (CAF) is decided to group machines into machine cell. Machines are grouped in the machine cell if WLF of the machine is greater than or equal to the decided CAF, otherwise rejected.

The assignment of parts to the individual cell is done by using equation (2) [13].

$$P_i = X_i \times P_j\,(X_i) \qquad \cdots(2)$$

Where,

P_i = Frequency of operations in the i[th] cell

X_i = Number of operations in a cell

$P_j\,(X_i)$ = Probability of the j[th] job = 1/ N_j

N_j = Number of operations in a job.

A component is assigned to the cell where it has scored a highest point as per equation (2).

2.2 Generation of Initial Feasible Solution

The proposed design has following assumptions:

1. Intracell distance of machines is considered unity
2. The capacity of each machine is same.
3. The cell design considers the processing time only, without considering setup time and waiting time
4. Machine breakdown is not considered
5. Backorders nil.
6. Intercell and Intracell cost, Processing times and Machine relocation cost is known.
7. All machines are available before starting actual production.

Design Objectives

The objective of Design of CMS is:

1. Minimization of a number of intercell movements and total manufacturing costs.
2. Maximum utilization of machines and cells.

NOTATIONS

Indices

c = Manufacturing cells index
m = Machine types index
p = Part types index

Input Parameters

CO_m = Cost of machine ‘m’
γ = Intercell movement cost per batch
β = Intracell movement cost per batch
V_p = Volume of part ‘p’
PT_{mp} = Processing time of part ‘p’ on machine ‘m’
T_m = Total time available on machine type ‘m’
α = Processing cost of part ‘p’ on machine / hour
δ_m = Relocation cost of machine type ‘m’
C_p= Cost of each part ‘p’

Decision Variables

N_{mc} = Number of machines m in the cell ‘c’
N_{cp} = The number of cells that part ‘p’ has to visit to meet its processing requirement.
NM_{pc} = Number of machines in cell ‘c’ on which part p’s processing requirements.
K^+_{mc} = Number of machines ‘m’ added in cell ‘c’
K^-_{mc} = Number of machines ‘m’ removed from cell ‘c’
AU=Intracell machine load unbalance
IU = Intercell machine load unbalance
LB = Minimum number of cells in CMS design
UB = Maximum number of cells in CMS design

Constraints

The following constraints are imposed on the model

1. Machine capacity to produce the specified product mix in each period is sufficient.
2. Upper and lower bounds are considered in cell size.
3. The number of cells is specified.

Mathematical Formulation

The objective function is written in an equation form as follows:

Minimization:

$$\sum_{c=1}^{C}\sum_{m=1}^{M} N_{mc}\times CO_m + \sum_{c=1}^{C}\sum_{p=1}^{P}(N_{cp}-1)\times\gamma + \sum_{c=1}^{C}\sum_{p=1}^{P}(N_{mc}-1)\times\beta$$

$$\sum_{m=1}^{M}\sum_{p=1}^{P}\left(\frac{V_p\times PT_{mp}}{T_m}\right)\times\alpha + \left[T_m - \sum_{m=1}^{M}\sum_{p=1}^{P}\left(\frac{V_p\times PT_{mp}}{T_m}\right)\times\alpha\right] + \sum_{c=1}^{C}\sum_{m=1}^{M}\delta m\,(K^+_{mc} - K^-_{mc})$$

$$+(AU+IU)\times\sum_{p=1}^{P}(V_p\times C_p) \qquad \cdots(3)$$

Subject to:

$$\sum_{m=1}^{M}\sum_{p=1}^{P}\left(\frac{V_p * PT_{mp}}{T_m}\right) \le T_m * N_{mc} \qquad \cdots(4)$$

$$\sum_{m=1}^{M} N_{mc} + \sum_{m=1}^{M} K^+_{mc} - \sum_{m=1}^{M} K^-_{mc} \ge LB \qquad \ldots(5)$$

$$\sum_{m=1}^{M} N_{mc} + \sum_{m=1}^{M} K^+_{mc} - \sum_{m=1}^{M} K^-_{mc} \le UB \qquad \ldots(6)$$

$$N_{mc},\, K^+_{mc},\, K^-_{mc} = \text{integer}$$

The Objective function in the equation (3) minimizes total cost. Objective function represents the cost of all machines, intercell material handling cost, intracellular material handling cost, operating cost, cost of underutilization of machines and machine relocation cost. The cost of the initial feasible solution is calculated by using equation (3) [14].

2.3 Design of Cell Configuration

The initial feasible solution is improved by SA to minimize the cost of CMS.

2.4 Optimum Design of CMS

The allocation of all machines is continuing various cell till minimization total cost of CMS through iterations.

III. CASE STUDY

The CMS was implemented in a manufacturing company, which was in the functional layout arrangement. Following points were considered in the implementation.

1. Three manufacturing cells are considered as per space availability in the company as per management's requirement. The cell consists of minimum two and maximum ten machines.
2. The Machines-Parts matrix was prepared for each period, which gives volume of parts, processing time (in hours) for total volume of each part type, total workload on each machine, cost of total parts, cost of each machine, processing cost / hour, relocation cost of machines, operation sequence and total operations on each part type (Machines-Parts matrix not given here due to space limitations).
3. Each entry in the Machine - parts matrix gives processing time for the total volume of each part type. The processing cost includes operating, labor and depreciation of machine costs.
4. The industry is working for 6 days/week and 8 hours/day.
5. Two-period planning was considered.
6. Simulated Annealing algorithm was developed in C language for the design of CMS.
7. Intercell movement cost was Rs. 100 and intracell movement cost was Rs. 30 for a batch. Batch size was different for each part type as per the weight and size.
8. Relocation cost was Rs. 10,000 per machine.

Final Cell arrangement with a number of machines is shown in Table 1 for period 1 and 2. Period 1 consists of 25 machines and 12 parts and period 2 consists of 26 machines and 13 parts. Computational results after implementation of period 1 and 2 are also shown in Table 2.

IV. CONCLUSIONS

Following conclusions are made after implementation of CMS.

1. When functional layout was converted into CMS in period 1, there was the reduction in intercell movement cost, intracell movement cost and overall cost of CMS.
2. For complete processing of parts in the same cell, there should be at least one machine from each machine group in a cell.
3. Cell balancing reduces underutilization of cells and WIP.
4. Starting next week schedule on underutilized machines can minimize underutilization cost.

The same algorithm can be extended for considering an intracell and intercell arrangement of all cells with actual distances. The design of CMS may be limited to certain industry sectors, which are having a product mix with the similarity of the operation sequence in manufacturing.

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Table 1: Final cell arrangement for period 1 and 2

PERIOD	CELL	MACHINES	PART FAMILY		C.L.	BR	CNC L.	H	S	GR
1 (25 × 12)	1	3,5,7,10,11,12,14,17,22,23 (10)	2,4,9,10,12 (05)	Required M/C hours	126.9	20	58.5	209.9	94.5	72
				Available M/C hours	96	48	48	192	48	48
	2	1,6,8,16,21,24 (06)	1,5,8 (03)	Required M/C hours	52	18	37.5	45	35	15
				Available M/C hours	96	0	48	48	48	48
	3	2,4,9,13,15,18,19,20,25 (09)	3,6,7,11 (04)	Required M/C hours	77.7	10	44.5	100	61.5	49
				Available M/C hours	96	0	48	144	96	48
	1,2 &3			Required M/C hours	256.7	48	140.5	354.9	191	136
				Available M/C hours	288	48	144	384	192	144
				Excess capacity	31.3	0	3.5	29.1	1	8
2 (26 × 13)	1	2, 4, 9, 15, 16, 20, 23, 25 (08)	1, 3, 5, 7, 10 (05)	Required M/C hours	110.5	40	59	116	71	40
				Available M/C hours	96	0	48	96	96	48
	2	3, 5, 7, 10, 12, 13, 14, 22, 24 (09)	2, 4, 6, 9 (04)	Required M/C hours	83	20	44.5	114.5	60	47
				Available M/C hours	96	48	48	144	48	48
	3	1, 6, 8, 11, 17, 18, 19, 21, 26 (09)	8, 11, 12, 13 (04)	Required M/C hours	87	28	38	134	53.5	50
				Available M/C hours	96	48	48	144	48	48
	1,2 &3			Required M/C hours	280.5	88	141.5	364.5	184.5	137
				Available M/C hours	288	96	144	384	192	144
				Excess capacity	7.5	8	2.5	19.5	7.5	7

(C. L. – Center lathe, BR – Broaching, CNC L. – CNC Lathe, H – Hobbing, S – Shaving Machine, GR - Grinding)

Table 2: Computational Results for period 1 and 2

SR NO.	PARTICULAR	FUNCTIONAL LAYOUT	PERIOD 1 (25 × 12)	IMPROVEMENTS	PERIOD 2 (26 × 13)	IMPROVEMENTS
1	Intercell movement cost (Rs.)	12000	8100	Reduced as compared to functional layout	8100	Reduced as compared to functional layout
2	Intracell movement cost (Rs.)	2340	NIL	100 % Reduction in intracell cost	NIL	100 % Reduction in intracell cost
3	Parts blocked due to unbalance in cells (Rs.)	1, 09, 800	47,658.2	8.633 % (of total parts cost)	32, 783.37	2.89% (of total parts cost)
4	Processing cost	2, 51,764	2, 86,973	--	3, 18, 855	--
5	Total parts cost	3, 66, 000	5, 52, 000	--	11, 34, 000	--
6	Total machines cost	5, 79, 80,000	6, 42, 80,000	--	6, 82, 80,000	--
7	Reallocation cost	--	30,000	--	20,000	--
8	**Total CMS Cost**	**5, 83, 77, 259**	**6, 46, 69, 028.2**	**--**	**6, 86, 76,403.36**	**--**