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Cellular Manufacturing System with Dynamic Lot Size Material Handling

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Abstract. Material Handling take as important role in Cellular Manufacturing System (CMS) design. In several study at CMS design material handling was assumed per pieces or with constant lot size. In real industrial practice, lot size may change during rolling period to cope with demand changes. This study develops CMS Model with Dynamic Lot Size Material Handling. Integer Linear Programming is used to solve the problem. Objective function of this model is minimizing total expected cost consisting machinery depreciation cost, operating costs, inter-cell material handling cost, intra-cell material handling cost, machine relocation costs, setup costs, and production planning cost. This model determines optimum cell formation and optimum lot size. Numerical examples are elaborated in the paper to ilustrate the characterictic of the model.

Keywords: Cellular Manufacturing Systems, Material Handling, Dynamic Lot Size

1. Introduction

Companies required to have competitive advantages like low cost, high quality product, excellence delivery time and flexibility in order to win global market environment [8]. Shorter product life cycle and demand changes are become main factors faced as a challence by the companies [12]. Cellular

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Manufacturing System (CMS) have been proposed as an alternative job shop and flowshop which help firms to achieve this goals [1], [2].

Cellular Manufacturing System has been intensively studied in the last three decades [10]. Former CMS studied Cellular Formation Problem to minimize inter and intracell material handling cost [1], [7]. In the next papers some related factor found in shop floor are included such as atlternative processing time, capacity planning, reconfiguration cost [13] and setup cost [10]. Some of recent studies in CMS considers new factors like Production planning, worker assignment, machine breakdown, worker flexibility, machine breakdown and scheduling, lay out problem. CMS can be categorized in sequential approach and concurrent approach [10]. In sequential approach the new factors is studied after Cell Formation Problem while in the current approach CFP and the new factors are sonsidered simulatneously [10]. To solve the CMS problem there are researchers use Integer Linear Programming method [7], [10], [11], [13] and use metaheuristic approach such as Genetic Algorithm [16], Simulated Annealing [6], Particle Swarm Optimization [8], and other metaheuristic method. Some advantages of metaheuristic approach are shorter computational time required in solving problem and best solution near optimal solution found by using Integer Linear Programming method [6]. Generally parameter data taken on that papers are deterministic but some researchers consider stochastic parameter and uncertainty in the related factor. As an example processing time taken as a stochatic parameter in CMS model [15], and demand is considered as uncertainty factor [11]. Dynamic lot sizing was studied by some researcher in CMS area and other area [2], [3]. [4], [5], [8].

Material Handling take as important role in Cellular Manufacturing System (CMS) design. In several study at CMS design material handling was assumed per pieces or with constant lot size. In real industrial practice, lot size may change during rolling period to cope with demand changes. This study develops CMS Model with Dynamic Lot Size Material Handling. Integer Linear Programming is used to solve the problem. Objective function of this model is minimizing total expected cost consisting machinery depreciation cost, operating costs, inter-cell material handling cost, intra-cell material handling cost, machine relocation costs, and setup costs. This model determines optimum cell formation and optimum lot size. Numerical examples are elaborated in the paper to ilustrate the characterictic of the model.

In the next section, we discuss the underlying assumptions and introduce a mathematical model of the problem presented in section 2. A numerical example and computational result are presented in section 3 and section 4, respectively. And the paper concludes with section 5.

Table 1. The summary of literature review

Studies	Cell Formation Problem	Alternative routing	Tool assignment problem	Machine breakdown	Production planning	Worker assignment	Dynamic lot size
[2]	-	-	√	-	-	-	√
[4]	-	-	-	√	-	-	√
[9]	√	√	-	-	-	√	-
[10]	√	√	-	-	-	-	-
[11]	√	√	-	-	√	√	-
[13]	√	√	-	-	-	-	√
[1]	√	-	-	-	-	-	-
[5]	-	-	-	-	-	-	√
Presented paper	√	√	-	√	√	-	√

2. Mathematical formulation

The Proposed Model is developed closely follows the presentasion model of main reference model [3], [10], and [14]. This study proposed CMS with dynamic lot size material handling. The objective function is minimizing the total cost of the CMS layout design and production planning cost. The total cost consists of machinery depreciation cost, operating costs, inter-cell material handling cost, intra-cell material handling cost, machine relocation costs, holding cost, back order cost and subcontract cost.

Assumption:

Following assumptions are made for the development of the model:
Operating time and demand are known and deterministic. Demand may change at each planning periods. Operating cost, amortized cost, relocation cost, setup cost of manufactured item and setup cost for remanufacturing item, holding cost, back order cost, subcontract cost are known. Number of machine is fixed during planning periods.

Notation

Index

C	index for *manufacturing cell* ($c=1, \ldots, C$)
m	index for machine type ($m=1, \ldots, M$)
p	index for part type ($p=1, \ldots, P$)
j	index for operation need by part p ($j=1, \ldots, Op$)
h	index for time periods ($h=1,\ldots,H$)

Parameter Input

P	number of part type
O_p	number of operation for each part types
M	number of machine types
C	maximum number that cell can be developed
H	number of periods
C^{inter}	inter-cell material handling cost per batch
C^{intra}	intra-cell material handling cost per batch
C^{re}	*redesign* cost including *install*, *shifting* dan *uninstalling*
$C^{amor}{}_m$	amortized cost of machine of type m per period
$C^{oper}{}_m$	operating cost of machine type m for each unit time
R^{inter}	inter-cell material handling cost
R^{setup}	Setup cost
R^{intra}	intra-cellmaterial handling cost
R^{re}	redesign cost including install, shifting and uninstalling
R^{ppic}	Production planning and inventory control cost
$Setup_{pm}$	setup cost per batch for part p pada mesin m { \$/mesin}
S_{jpm}	setup cost for individual operation j for part p at machine type m {\$/operasi}
a_{jpm}	$= 1$, if operation j of part type p can be done on machine type m; 0, otherwise
t_{jpm}	processing time required to process operation j of part type p on machine type m (hour)
T_m	time capacity of machine m in terms of unit time (hours) for each period.
D_{ph}	demand for part type p at period h
λ_{ph}	Unit sub contracting cost of part type p in period h
ψ_{ph}	Unit holding cost of part type p in period h
ρ_{ph}	Unit backorder cost of part type p in period h
Lc	Lower bound for cell size in term of machine types
Uc	Upper bound for cell size in term of machine types
A_m	The number of available machines of type m
LB	Lower bound for subcontracting parts

UB	Upper bound for subcontracting parts
A	An arbitrary big positive number

Decision variable

B^{intra}_{ph}	Intra Material handling lot size of part type *p* at period *h*
B^{inter}_{ph}	Inter Material handling lot size of part type *p* at period *h*
B^{prod}_{ph}	Production lot size of part type *p* at period *h*
N_{mch}	Number of machines of type *m* assigned to cell *c* in period *h*
K^{+}_{mch}	Number of machine type *m* added in cell *c* in period *h*
K^{-}_{mch}	Number of machine type *m* removed in cell *c* in period *h*
Q_{ph}	Number of demand of part type *p* to be produced in period *h*
S_{ph}	Number of demand of part type *p* to be subcontracted in period *h*
I_{ph}	Inventory level of part type *p* at end of period *h*; $I_{p0}=I_{pH}=0$
B_{ph}	Backorder level of part type *p* at end of period *h*; $B_{p0}=B_{pH}=0$
Y_{ph}	1, if $Q_{ph}>0$; 0 otherwise
Y'_{ph}	1, if $I_{ph}>0$ and equals to 0 if $B_{ph}>0$
X_{jpmch}	1, if operation *j* of part type *p* is done on machine type *m* in cell *c* in period *h*; 0 otherwise

Objective Function
Minimize

$$Z^f = \sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{m=1}^{M} N_{mch}C_m^{amor} + \sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{O_p}\sum_{m=1}^{M} C_m^{oper} D_{ph} t_{jpm} x_{jpmch} + \sum_{p=1}^{P}\sum_{h}^{H}\left(\sum_{m=1}^{M}\left\lceil\frac{Q_{ph}}{B_{ph}^{prod}}\right\rceil Setup_{pm} + \sum_{p=1}^{P}\left(\sum_{m=1}^{M}\sum_{j=1}^{O_p} S_{jpm}x_{jpmc}\right)D_p\right) + \frac{1}{2}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\left\lceil\frac{Q_{ph}}{B_{ph}^{intra}}\right\rceil C^{intra}\left(\sum_{m=1}^{M}\left|x_{j+1pmch} - x_{jpmch}\right| - \left|\sum_{m=1}^{M} x_{j+1pch} - \sum_{m=1}^{M} x_{jpch}\right|\right) + \frac{1}{2}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\left\lceil\frac{Q_{ph}}{B_{ph}^{inter}}\right\rceil C^{inter} \times \left|\sum_{m=1}^{M} x_{(j+1)pmch} - \sum_{m=1}^{M} x_{jpmch}\right| + \frac{1}{2}\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{m=1}^{M} C^{re}(K_{mch}^{+} + K_{mch}^{-}) + \sum_{h=1}^{H}\sum_{p=1}^{P} \psi_{ph}I_{ph} + \rho_{ph}B_{ph} + \lambda_{ph}\, S_{ph} \quad (1)$$

Contraints

$$\sum_{p=1}^{P}\sum_{j=1}^{Op} D_{ph}.\, t_{jph}X_{jpmch} \le T_m N_{mch} \qquad \forall m,c,h \quad (2)$$

$$Q_{ph} + I_{p(h-1)} - B_{p(h-1)} - I_{ph} + B_{ph} + S_{p(h-1)} = D_{ph} \qquad \forall p,h \quad (3)$$

$$\sum_{c=1}^{C}\sum_{m=1}^{M}\sum_{j=1}^{O_p} X_{jpmch} \le AQ_{ph} \;\forall p,h \quad (4)$$

$$N_{mc(h-1)} + K_{mch}^{+} - K_{mch}^{-} = N_{mch} \quad \forall m,c,h \quad (5)$$

$$\sum_{m=1}^{M} N_{mch} \ge Lc \qquad \forall c,h \quad (6)$$

$$\sum_{m=1}^{M} N_{mch} \le Uc \qquad \forall c,h \quad (7)$$

$$\sum_{c=1}^{C} N_{mch} \le A_m \qquad \forall m,h \quad (8)$$

$$\sum_{c=1}^{C}\sum_{m=1}^{M} a_{jpm}X_{jpmch} = Y_{ph} \;\forall j,p,h \quad (9)$$

$$LB \le S_{ph} \le UB \quad \forall p,h \quad (10)$$

$$I_{pH} - B_{pH} \quad \forall p \quad (11)$$

$$Q_{ph} \le A\, Y_{ph} \quad Q_{ph} \ge Y_{ph} \qquad \forall p,h \quad (12)$$

$$I_{ph} \le A\, Y'_{ph} \quad B_{ph} \le A\,(1 - Y'_{ph}) \qquad \forall p,h \quad (13)$$

$$N_{mch}, K_{mch}^{+}, K_{mch}^{-}, Q_{ph}, S_{ph}, I_{ph}, B_{ph} \ge 0 \text{ and integer}, X_{jpmch}, Y_{ph}, Y'_{ph} \in \{0,1\} \quad (14)$$

The objective function the model is minimizing total CMS design cost (1) which is consists of amortized cost, operating cost, setup cost, intra-cell material handling cost, inter-cell material handling cost, and production planning and inventory control cost. Equation (2) is capacity constraint ensures machine capacity is not exceeded and determines the number of each machine type in each cell, Constraint (3) is material balance well known equation which creates equivalency for all parts quantity level between three consecutive periods. Constraint (4) shows that if a part has not been produced in a period or Q_{ph}=0 none of its operation should have been dedicated to a machine, and cell. Balance constraint (5) ensures the number of machines is always the same after reconfiguring has been conducted. Constraints (6) and (7) indicate lower and upper bound for cell size respectively. Constraint (8) guarantees number of machine type allocated to all cells in each period will not exceed number of available machines from that type in this period. Constraint (9) ensures that if a partial portion of part demands must be produced in a specific period, each required operation for processing that part on its related machine in each period just could have been assigned to one cell and be done only by one worker who is able to work on that machine. Constraint (10) indicates lower and upper bound for subcontracting quantity for each part in each period. Constraint (11) expresses that inventory and backorder level must be zero at the end of periods. Constraint (12) is supplementary for constraint 9. If necessary operations for processing parts in equation 9 can be done, then some portion of demand could be produced in that specific period. Constraint (13) ensures that inventory and backorder cannot happen simultaneously. Constraint (14) determines the type of decision variables.

3. Numerical Example

The Numerical test use data taken from [14] by modifying planning period become three periods and removing unnecessary information like worker information. Example consist data as follows:

Table 2. Machine Information

Machine type	Machine Information			
	C^{amor}_m	C^{oper}_m	C^{re}_m	T_m
1	1200	8	400	500
2	1500	4	600	500
3	1800	6	500	500

Table 2. Part information.

Part type	Part Information							
	D_{p1}	D_{p2}	D_{p3}	λ_p	ψ_p	ρ_p	C^{inter}_p	C^{intra}_p
1	0	600	320	3	2	14	25	5
2	240	0	500	6	3	12	30	6
3	400	440	0	9	2	10	15	3

Table 3. Operation-part-machine matrix includes processing time and setup cost

machine	Part 1		Part 2		Part 3	
	O_1	O_2	O_1	O_2	O_1	O_2
1	0.4,6	0,0	0.3,5	0,0	0,0	0.1,7
2	0.2,8	0,0	0,0	0.4,6	0.3,7	0,0
3	0,0	0.3,7	0.2,8	0,0	0.1,5	0,0

4. Result and Analysis

Solution of the problem solved using Branch and bound method running in computer with spec AMD A4-1250APU RAM 4 GB HD 320 GB. After 60 minutes running in, best solution can be reprented in Table 4, Table 5, and Table 6.

Table 4. Objective function value of the problem.

Zi*	Holding	Sub-contracting	Intercell	Intracell	Constant cost	Variable cost	Setup	relocation cost
29416	553	240	0	855	14700	10488	104	300

Table 5. Production plan for the problem

	Period 1			period 2			period 3		
	part 1	part 2	part 3	part 1	part 2	part 3	part 1	part 2	part 3
subcontracting	0	0	0	0	80	0	0	0	0
backorder	0	0	0	0	0	0	0	0	0
holding	0	0	0	26	167	0	0	0	0
production	0	240	400	626	167	440	214	333	0
demand	0	240	400	600	0	440	320	500	0

Table 6. Parts, machines assignment to cells resulted from minimizing total cost

	part			machines		
	Cell 1	Cell 2	Cell 3	Cell 1	Cell2	Cell 3
period 1	p1, p2, p3	p1	p2, p3	m1, m2, m3	m1, m2, m3	m1, m2 m3
period 2	p1, p2, p3	-	p2, p3	m1, m2, m3	m1, m1, m2, m3	m1, m2, m3
period 3	p1, p2, p3	-	p2, p3	m1, m2, m3	m1, m2, m3	m1, m2, m3

Table 7. Lot size production, lot size intercell materiall material handling, lot size intercell material handling

Lot size	Period 1			period 2			period 3		
	part 1	part 2	part 3	part 1	part 2	part 3	part 1	part 2	part 3
production	25	25	25	25	25	25	25	25	25
intercell	18	24	24	20	24	24	23	24	25
intracell	25	25	25	25	25	25	25	25	25

From Table 4. above we can see that numerical test give result total cost $29416 which is consist of holding cost $553, subcontracting cost $870, intercell $0, intracell material handling cost $855, costan cost $10488, setup cost $2269, relocation cost $300. Intercell material handling cost is zero because material handling all done in intracell. From Table 5. We can conclude production planning in the whole planning period whic is consist of number subcontracting, number holding unit, number back order, and number item to be produced. As an example Demand 500 unit for part 2 in period 3 satisfied by 333 unit produced in period 3 and 177 unit produced in period 2. From Table 6. We can conclude part and machine assignment to cells in each period. As an example there is one machine type 1 added in cell 2 in period 2 and to be remove at period 3. From table 7 we can see lot size production, lot size intercell material handling, and intracell material handling. Note lot size in Table 7. is the best solution computational result after 60 minutes running. Global optimum solution needs extra computational times because this problem is NP-Hard problem.

5. Conclusion

In the current work we thoroughly develop CMS Model with Dynamic Lot Size Material Handling. Integer Linear Programming is used to solve the problem. Objective function of this model is minimizing total expected cost consisting machinery depreciation cost, operating costs, inter-cell material handling cost, intra-cell material handling cost, machine relocation costs, and setup costs. This model determines optimum cell formation and optimum lot size. Suggestion for further research can be guided as follows: application of metaheuristic to solve the model, incorporating other variables in production planning.

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