Cellular Manufacturing System Model under Demand Uncertainty

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Abstract. In real-world problems, designing Cellular Manufacturing System (CMS) face the imprecise or fuzzy nature data such as demand uncertainty. Due to these considerations, this study proposes Dynamic CMS model under demand uncertainty. Dynamic CMS is a CMS where its machine-cell configuration may change during the planning period due to the demand changes. This model optimizes Cell Formation, Production planning and Worker assignment concurrently. 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, back order cost, holding cost, subcontracting cost, worker assignment cost. This model determines optimum cell formation, production optimum policy (like determining quantity of production, inventory and subcontracting parts) and workers optimum assignment to manufacturing cells in each rolling period. The proposed model is an integer linear programming model. Numerical examples are elaborated in the paper to depict the influence of changes in fuzzy demand and fuzzy capacity on changes in total cost, and in production and worker optimum policy

Keywords: CMS, Production Planning, Worker Assignment, Fuzzy Demand

1. INTRODUCTION

Cellular Manufacturing System (CMS) is a well known manufacturing system derived from Group Technology concept. The advantages of CMS is combining the flow shop's speed and efffiency, and job shop's flexibility (Khannan, 2012b). So, it is suitable for high volume dan high variety demand environment.

Basic CMS was developed to minimize material handling cost (Ebara *et al.* 2006). In the next researcher Cell Formation Problem was introduced by considering several related cost such as machinery depreciation cost, operating costs, inter-cell material handling cost, intra-cell material handling cost, machine relocation costs, and setup costs (Jayakumar, 2010; Khannan, 2012a; and Khannan, 2012b). Cell Formation based on Garbie *et al.(*2008) can be divided into two categories: Robust CMS (Pillai, 2007), (Ebara, 2006), (Askin, 1997) and Dynamic CMS

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(Jayakumar, 2010), (Javadian, *et al.* 2011). In Robust CMS the Cell Formation is fix during the whole planning period while Redesigning CMS the Cell Formation is reconfigurable in the rolling period.

Shorter product life cycle and variation of product mix let production planning variable such as inventory level, back order, production quantity and subcontracting quantity being considered in the CMS design. Several researchers consider production planning such as Mahdavi *et al.* (2010) and Niaki *et al.* (2011).

Worker is the main role in processing part in the manufacturing cell. Mahdavi *et.al.* (2009) considers worker flexibility, Mahdavi *et.al. (2010)* add worker assignment problem (include: hiring cost, firing cost, training cost) in the CMS design problem. Demand and Machine capacity in Mahdavi's model is deterministic. The recent researches such as Mohammadi (2014) use efficient Genetic Algoritm to solve lay out problem in CMS with processing routings and subcontracting approach. Negahban (2014) give literature review and analysis the use of simulation in CMS design.

In real-world problems, designing Cellular Manufacturing System (CMS) faces the imprecise or fuzzy nature data such as demand uncertainty. Ghezavati (2010) design integrated cellular manufacturing system with scheduling considering stochastic processing time. Safaei (2007) has developed interesting fuzzy programming approach to solve uncertainty problem but did not consider production planning and worker assignment yet. Due to these considerations, this study proposes CMS model under demand uncertainty. In this paper integrated model was developed to optimize Cell Formation, Production planning and Worker assignment concurrently. This model uses the integer linear programming to solve the problem.

2. THE MATHEMATICAL MODEL

Proposed Model was developed mostly based on Safaei *et al.* (2007), Niai, *et al.* (2011), and Khannan&Maruf (2012). This study proposed CMS model under demand uncertainty. 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, back order cost, holding cost, subcontracting cost, and worker assignment cost. This model determines optimum cell formation, production optimum policy (like determining quantity of production, inventory and subcontracting parts) and workers optimum assignment to manufacturing cells in each rolling period.

Asumptions:

Following assumptions are made for the development of the model. The demand is a fuzzy quantities. Machine capacity, operating time, operating cost, amortized cost, relocation cost and setup cost are known and deterministic. 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 ($h=1,\ldots,H$)
w	Index for worker types (w=1,...,W)

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
W	Number of worker types
B_p^{inter}	batch size for inter-cell movements of part type p
B_p^{intra}	batch size for inter-cell movements of part type p
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^{intra}	intra-cellmaterial handling cost (redesign)
R^{re}	redesign cost including install, shifting and uninstalling (redesign)
$Setup_{pm}$	setup cost for part p pada mesin m { \$/mesin}
S_{jpm}	setup cost for individual operation j for part p at machine type m {\$/operasi}
UB	maximal cell size i.e., maximum number of machines per cell
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
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)
Lc	Lower bound for cell size in term of machine types
Uc	Upper bound for cell size in term of machine

	types
Uw	Upper bound for cell size in term of number of workers
Am	The number of available machines of type *m*
Aw	The number of available workers of type *w*
LB	Lower bound for subcontracting parts
UB	Upper bound for subcontracting parts
$UB_{Lmachin}$	Maximum number of machines which a worker can serve
P_{mw}	1 if worker type *w* is ready to work on machine type *m* or be able to acquire capability of working on machine by training; otherwise
ϕ_{mw}	Training cost per time unit of worker w for attaining performing skill on machine type m for a worker who can get necessary skill of working on machine by training
T_m	Required time for training a worker who serves machine type *m* in terms of time unit
H_{wh}	Hiring cost of worker type *w* within period *h*
F_{wh}	Firing cost of worker type *w* within period *h*
S_{wh}	Salary cost of worker type *w* within period *h*
T_{mh}	Available time for machine type *m* in the period *h*
T_{wh}	Available time for worker type *w* in the period *h*
A	An arbitrary big positive number

Decision variable

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*
L_{mch}	Number of worker type *w* assigned to cell *c* in period *h*
L^{+}_{mch}	Number of worker type *w* added in cell *c* in period *h*
L^{-}_{mch}	Number of worker type *w* 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 $B_{ph}>0$
p_{mw}	1, if worker type *w* is used to work on machine type *m*; 0 otherwise
X_{jpmwch}	1, if operation *j* of part type *p* is done on machine type *m* with worker *w* in cell *c* in period h; 0 otherwise

3. Proposed Model

The proposed model is as follows:

1. **Standard Model**

Min Z = Z($\mathbf{D}^{H}_{ph}$) s.t. constraint 3 to constraint 21 $\sum_{p=1}^{P}\sum_{j=1}^{Op}\sum_{w=1}^{W} X_{jpmwch} t_{jpm} Q^{H}_{ph} \le T^{L}_{mh} N_{mch}\ \forall m,c,h$ $Q_{ph}+I_{p(h-1)}-B_{p(h-1)}-I_{ph}+B_{ph}+S_{p(h-1)}=D^{H}_{ph}\quad \forall p,h$ Prob 1. High demand	Min Z = Z($\mathbf{D}^{L}_{ph}$) s.t. constraint 3 to constraint 21 $\sum_{p=1}^{P}\sum_{j=1}^{Op}\sum_{w=1}^{W} X_{jpmwch} t_{jpm} Q^{L}_{ph} \le T^{H}_{mh} N_{mch}\ \forall m,c,h$ $Q_{ph}+I_{p(h-1)}-B_{p(h-1)}-I_{ph}+B_{ph}+S_{p(h-1)}=D^{L}_{ph}\quad \forall p,h$ Prob 2. Low demand

Objective Function

$$Z^{f} = R^{amortized} + R^{operating} + R^{setup} + R^{intra} + R^{inter} + R^{relocation} + R^{ppic} + R^{hirefire} + R^{training} + R^{salary} \qquad (1)$$

Constraint

$$\sum_{p=1}^{P}\sum_{j=1}^{Op}\sum_{w=1}^{W} X_{jpmwch} t_{jpm} Q_{ph} \le T_{mh} N_{mch}\ \forall m,c,h \qquad (2)$$

$$\sum_{c=1}^{C}\sum_{j=1}^{Op}\sum_{m=1}^{M} X_{jpmwch} t_{jpm} Q_{ph} \le L_{wch}\ T_{wh}\ \forall j,p,h \qquad (3)$$

$$Q_{ph}+I_{p(h-1)}-B_{p(h-1)}-I_{ph}+B_{ph}+S_{p(h-1)} = D_{ph}\quad \forall p,h \qquad (4)$$

$$\sum_{c=1}^{C}\sum_{m=1}^{M}\sum_{j=1}^{Op}\sum_{w=1}^{W} X_{jpmwch} \le AQ_{ph}\ \forall p,h \qquad (5)$$

$$N_{mc(h-1)}+K^{+}_{mch}-K^{-}_{mch}=N_{mch}\quad \forall m,c,h \qquad (6)$$

$$L_{wc(h-1)}+L^{+}_{wch}-L^{-}_{wch}=L_{wch}\quad \forall w,c,h \qquad (7)$$

$$\sum_{m=1}^{M} N_{mch} \ge Lc\qquad \forall c,h \qquad (8)$$

$$\sum_{m=1}^{M} N_{mch} \le Uc\qquad \forall c,h \qquad (9)$$

$$\sum_{w=1}^{W} L_{wch} \le Uw\qquad \forall c,h \qquad (10)$$

$$\sum_{c=1}^{C} N_{mch} \le A_{m}\qquad \forall m,h \qquad (11)$$

$$\sum_{c=1}^{C} L_{wch} \le A_{w}\qquad \forall w,h \qquad (12)$$

$$p_{mw} \le P_{mw}\qquad \forall w,m \qquad (13)$$

$$\sum_{w=1}^{W} p_{mw} = 1\qquad \forall m \qquad (14)$$

$$\sum_{m=1}^{M} p_{mw} \le UB_{LMachine}\qquad \forall c,h \qquad (15)$$

$$\sum_{c=1}^{C}\sum_{m=1}^{M}\sum_{w=1}^{W} a_{jpm} X_{jpmwch} = Y_{ph}\ \forall j,p,h \qquad (16)$$

$$\mathrm{LB} \le \mathrm{S}_{ph} \le \mathrm{UB} \quad \forall p, h \tag{17}$$

$$\mathrm{I}_{pH} - \mathrm{B}_{pH} \quad \forall p \tag{18}$$

$$\mathrm{Q}_{ph} \le \mathrm{A}\,\mathrm{Y}_{ph} \quad \mathrm{Q}_{ph} \le \mathrm{Y}_{ph} \quad \forall p, h \tag{19}$$

$$\mathrm{I}_{ph} \le \mathrm{A}\,Y'_{ph} \quad \mathrm{B}_{ph} \le \mathrm{A}\,(1 - Y'_{ph}) \quad \forall p, h \tag{20}$$

$$\mathrm{N}_{mch}, \mathrm{K}^{+}_{mch}, \mathrm{K}^{-}_{mch}, L_{wch}, \mathrm{L}^{+}_{wch}, \mathrm{L}^{-}_{wch}, \mathrm{Q}_{ph}, \mathrm{S}_{ph}, \mathrm{I}_{ph}, \mathrm{B}_{ph} \ge 0 \text{ and integer}, \mathrm{X}_{jpmwch}, \mathrm{p}_{mw}, \mathrm{Y}_{ph}, \mathrm{Y}'_{ph} \in \{0,1\} \tag{21}$$

(i). Amortized cost

$$R^{amortized} = \sum_{h=1}^{H} \sum_{c=1}^{C} \sum_{m=1}^{M} \mathrm{N}_{mch} \mathrm{C}_{m}^{amor} \tag{22}$$

(ii). Operating Cost

$$R^{operating} = \sum_{h=1}^{H} \sum_{c=1}^{C} \sum_{p=1}^{P} \sum_{j=1}^{O_p} \sum_{m=1}^{M} \sum_{w=1}^{W} C_{m}^{oper} \mathrm{Q}_{ph} \mathrm{t}_{jpm} \mathrm{X}_{jpmwch} \tag{23}$$

(iii). Setup Cost

$$R^{setup} = \sum_{p=1}^{P} \left(\sum_{m=1}^{M} \mathrm{Setup}_{pm} \; + \sum_{p=1}^{P} \left(\sum_{m=1}^{M} \sum_{j=1}^{O_p} \mathrm{S}_{jpm} \mathrm{X}_{jpmwch} \right) \mathrm{Q}_{ph} \right) \tag{24}$$

(iv). Intra-cell material handling cost

$$R^{intra} = \frac{1}{2} \sum_{h=1}^{H} \sum_{p=1}^{P} \sum_{j=1}^{O_p - 1} \sum_{c=1}^{C} \sum_{w=1}^{W} \left\lceil \frac{\mathrm{Q}_{ph}}{\mathrm{B}_{p}^{\mathrm{intra}}} \right\rceil \mathrm{C}^{\mathrm{intra}} \times \left(\sum_{m=1}^{M} \left| \mathrm{X}_{j+1pmwch} - \mathrm{X}_{jpmwch} \right| - \left| \sum_{m=1}^{M} \mathrm{X}_{j+1pmwch} - \sum_{m=1}^{M} \mathrm{X}_{jpmwch} \right| \right) \tag{25}$$

(v). Inter-cell material handling cost

$$R^{inter} = \frac{1}{2} \sum_{h=1}^{H} \sum_{p=1}^{P} \sum_{j=1}^{O_p - 1} \sum_{c=1}^{C} \sum_{w=1}^{W} \left\lceil \frac{\mathrm{Q}_{ph}}{\mathrm{B}_{p}^{\mathrm{inter}}} \right\rceil \mathrm{C}^{\mathrm{inter}} \times \left| \sum_{m=1}^{M} \mathrm{X}_{(j+1)pmwch} - \sum_{m=1}^{M} \mathrm{X}_{jpmwch} \right| \tag{26}$$

(vi). Relocation cost

$$R^{relocation} = \frac{1}{2} \sum_{h=1}^{H} \sum_{c=1}^{C} \sum_{m=1}^{M} \mathrm{C}^{\mathrm{re}} (\mathrm{K}^{+}_{mch} + \mathrm{K}^{-}_{mch}) \tag{27}$$

(vii). Production planning cost

$$R^{ppic} = \sum_{h=1}^{H} \sum_{p=1}^{P} \psi_{ph} \mathrm{I}_{ph} + \rho_{ph} \mathrm{B}_{ph} + \lambda_{ph}\, \mathrm{S}_{ph} \tag{28}$$

(viii). Hired and fired cost

$$R^{hirefire} = \sum_{h=1}^{H} \sum_{c=1}^{C} \sum_{w=1}^{W} \mathrm{H}_{wh} \mathrm{L}^{+}_{wch} + \mathrm{F}_{wh} \mathrm{L}^{-}_{wch} \tag{29}$$

(ix). Worker training cost

$$R^{training} = \sum_{m=1}^{M} \sum_{w=1}^{W} \mathrm{p}_{mw} \Phi_{mw} \mathrm{T}_{m} \tag{30}$$

(x). Worker salary cost

$$R^{salary} = \sum_{h=1}^{H} \sum_{c=1}^{C} \sum_{w}^{W} \mathrm{S}_{wh} \mathrm{L}_{wch} \tag{31}$$

The objective function of the standard model is minimizing total CMS design cost (1) which is consist of amortized cost (22), operating cost (23), setup cost (24), intra-cell material handling cost (25), inter-cell material handling cost (26), relocation cost (27), production planning cost (28), hired fired cost (29), worker training cost (30), and worker salary cost (31). Equation (2) is capacity constraint ensures machine capacity is not exceeded and determines the number of each machine type in each cell, Worker time Constraint (3) assures that available times for workers are not exceeded. Constraint (4) is material balance well known equation which creates equivalency for all parts quantity level between three consecutive periods. Constraint (5) 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, cell and worker. Balance constraint (6) ensures the number of machines is always the same after reconfiguring has been conducted. Balance worker Constraint (7) ensure number of available workers between three consecutive periods always the same. Constraints (8) and (9) indicate lower and upper bound for cell size respectively. Constraint (10) represents minimum number of workers that is assigned to each cell in each period. Constraint (11) 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 (12) shows that in each period, total number of workers allotted to all cells from type *w* should not be more than number of available workers from type *w* in that period. Constraint (13) ensures that worker type *w* must have allocated to a machine which is able to work on it. Constraint (14) guarantees that each machine can be served only by one worker. Constraint (15) controls upper bound for number of machines which worker *w* serves them. Constraint (16) 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 (17) indicates lower and upper bound for subcontracting quantity for each part in each period. Constraint (18) expresses that inventory and backorder level must be zero at the end of periods. Constraint (19) is supplementary for constraint 16. If necessary operations for processing parts in equation 16 can be done, then some portion of demand could be produced in that specific period. Constraint (20) ensures that inventory and backorder cannot happen simultaneously. Constraint (21) determines the type of decision variables.

Fuzzy programming
Max λ
Subject to
Constraint (3) to constraint (21) and

$$\lambda(Z_U - Z_L) =$$

$$\left(\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{m=1}^{M} \mathrm{N}_{mch}\mathrm{C}_{m}^{\mathrm{amor}} +\right.$$

$$\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{O_p}\sum_{m=1}^{M}\sum_{w=1}^{W} C_m^{\mathrm{oper}}\left[Q_{ph}\right]t_{jpm}\mathrm{X}_{jpmwch} \quad +$$

$$\sum_{p=1}^{P}\left(\sum_{m=1}^{M}\mathrm{Setup}_{pm} \quad +\sum_{p=1}^{P}\left(\sum_{m=1}^{M}\sum_{j=1}^{O_p}\mathrm{S}_{jpm}\mathrm{X}_{jpmwch}\right)Q_{ph}\right) +$$

$$\frac{1}{2}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\sum_{w=1}^{W}\left\lceil\frac{Q_{ph}}{\mathrm{B}_p^{\mathrm{intra}}}\right\rceil \mathrm{C}^{\mathrm{intra}} \times$$

$$\left(\sum_{m=1}^{M}\left|\mathrm{X}_{j+1pmwch} - \mathrm{X}_{jpmwch}\right| - \left|\sum_{m=1}^{M}\mathrm{X}_{j+1pmwch} -\right.\right.$$

$$\left.\left.\sum_{m=1}^{M}\mathrm{X}_{jpmwch}\right|\right) +$$

$$\frac{1}{2}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\sum_{w=1}^{W}\left\lceil\frac{Q_{ph}}{\mathrm{B}_p^{\mathrm{inter}}}\right\rceil \mathrm{C}^{\mathrm{inter}} \times$$

$$\left|\sum_{m=1}^{M}\mathrm{X}_{(j+1)pmwch} - \sum_{m=1}^{M}\mathrm{X}_{jpmwch}\right| +$$

$$\frac{1}{2}\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{m=1}^{M}\mathrm{C}^{\mathrm{re}}(\mathrm{K}_{mch}^{+} +$$

$$\mathrm{K}_{mch}^{-}) + \sum_{h=1}^{H}\sum_{p=1}^{P}\psi_{ph}\mathrm{I}_{ph} + \rho_{ph}\mathrm{B}_{ph} + \lambda_{ph}\ \mathrm{S}_{ph} +$$

$$\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{w=1}^{W}\mathrm{H}_{wh}\mathrm{L}_{wch}^{+} + \mathrm{F}_{wh}\mathrm{L}_{wch}^{-} +$$

$$\sum_{m=1}^{M}\sum_{w=1}^{W}\mathrm{p}_{mw}\phi_{mw}\mathrm{T}_m +$$

$$\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{w}^{W}\mathrm{S}_{wh}\mathrm{L}_{wch} \qquad (32)$$

$$\mathrm{Q}_{ph} + \mathrm{I}_{p(h-1)} - \mathrm{B}_{p(h-1)} - \mathrm{I}_{ph} + \mathrm{B}_{ph} + \mathrm{S}_{p(h-1)} =$$

$$(1-\lambda)\mathrm{D}_{ph}^{L} + \lambda\mathrm{D}_{ph}^{U} \qquad \forall p,h \qquad (33)$$

The objective function of fuzzy model is maximizing λ which is decision level indicates the degree of membership in the decision fuzzy set. Equation (32) is objective fuzzy constraint. Equation (33) is material balance constraint well known equation which creates equivalency for all parts quantity level between two consecutive periods. Demand given in fuzzy number.

4. NUMERICAL EXAMPLE

To illustrate and to check validity of the proposed model, two standard problems were solved by using branch-and-bound method. Numerical test use small sized data taken from Niaki *et.al.* (2011) by adding fuzzy number in demand and machine quantity. Example consists of 2 cells, 3 parts, 3 machines, 2 worker and 2 periods. Machine information and part information are shown in table 1 and table 2 respectively. Table 3 contain necessary a worker information data. The data set related to operation-part-machine is shown in table 4 includes processing time and setup cost. Table 5 show the objective solution value for the four standard problem includes total cost cost holding cost, back order cost, subcontracting cost, intercell movement cost, intra cell movement cost, constant cost, variable cost, setup cost, worker training cost, worker salary and relocation cost. Production plan decision variable shown in table 6 includes quantity number of subcontracting unit, backorder cost. Part, machines and worker assignment to cells in the rolling periods shown in table 7.

According to Table 5, Z_L = 17381. Z_U = 21571. By solving fuzzy programming model, optimum value of decision level and objective function is obtained as λ*=0.09 and Z(X*) is 21185. Parts, machines and worker assignment to cell resulted from maximizing decision problem under decision level λ^{best} =0.092 shown in table 7.

Table 1: Machine Information

Machine type	Machine Information						
	C^{amor}_{m}	C^{oper}_{m}	C^{re}_{m}	T_m	A_m	T_{m1}	T_{m2}
1	1200	8	400	30	2	500	500
2	1500	4	600	45	2	500	500
3	1800	6	500	25	2	500	500

Table 2: part information.

Part type	Part Information							
	D_{p1}	D_{p2}	λ_p	ψ_p	ρ_p	B_p^{inter}	B_p^{intra}	C^{inter}_{p}	C^{intra}_{p}

1	0	150-180	3	1	14	50	5	25	5
2	60-90	80-110	6	2	12	50	5	30	6
3	120-150	100-130	9	3	10	50	5	15	3

Table 3 machine-worker matrix and worker information

worker	Item1			(Φmw) machine										
	1	2	3	1	2	3	Hw1	Hw2	Fw2	Sw1	Sw2	Aw	Tw1	Tw2
1	1	0	1	0	1000	5	200	200	150	500	500	2	500	500
2	0	1	1	1000	5	0	200	200	150	500	500	2	500	500

Table 4: 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

Table 5: Objective function value of the two standard problems.

	Zi*	Holding	Sub-contracting	Intercell	Intracell	Constant cost	Variable cost	Setup	Training	Salary	relocation cost
Problem 1	21571	0	1740	105	1245	11700	3010	206	225	3000	337
Problem 2	17381	0	870	268	626	11400	1513	104	225	2000	375

Table 6: Production plan for the two standard problems

		period 1			period 2		
		part 1	part 2	part 3	part 1	part 2	part 3
Problem 1	Subcontracting		96	32	60	32	40
	backorder						
	holding						
	production		300		300	64	152
	demand		120	120	300	160	200
Problem 4	Subcontracting		48	24	30	16	20
	backorder						
	holding						
	production		150		150	32	76
	demand		60	120	150	80	100

Table 7: parts, machines and worker assignment to cells resulted from maximizing decision problem under decision level $\lambda^{best} = 0.092$

index		part		machines		worker	
		Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2
maximation	period 1	p1, p2, p3	p2, p3	m1, m2, m3	m1, m3	w2	w1

decision problem	period 2	p1, p2, p3	-	m1, m2,m3	-	w1, w2	-

5. CONCLUSION

This paper proposed a cellular manufacturing system model under demand uncertainty. Main advantage of the proposed model are: This model consider Cellular Formation Problem cost, Production Planning cost, and Worker Assignment cost simultaneously in uncertain condition. We can decide the number of production unit, subcontract unit, inventory unit in each rolling period by this model. We can slso decide parts, machines and worker type assignment to cells in each rolling periods. Fuzzy integer linear programming is computational hard so it need a long computational time. For further research there are some guidelines as follows: (1) Application of metaheuristic for large sized problem, (2) incorporating other variables related to production planning and worker assignment problem.

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APPENDIX

REFERENCES

Askin. R., Selim, H., and Vakharia, A., (1997) A Methodology for designing flexible cellular manufacturing systems, *IIE Transactions* 29 (7), pp. 599–610.

J.P. Ebara, H., Hirotani, D., Takahashi, K., and Morikawa, K. (2006) Cellular manufacturing system capable of responding to changes in demand, *Reconfigurable Manufacturing System and Transformable Factories*, III, 341-353, Springer-Verlag Berlin Heidelberg.

Garbie, I.H., Parsaei, H.R., and Leep, H.R. (2008) *Designing Cellular Manufacturing for Next Generation Production Systems, Collaborative Engineering: Theory and Practice,* Springer Science + Business Media, LLC.

Javadian, N., Aghajani, A., Rezaeian, J., and Sebdani, M.J.G. (2011) Multi-objective integrated cellular manufacturing systems design with dynamic system reconfiguration. *International Journal of Advanced Manufacturing Technology.*

Jayakumar, V. and Raju, R. (2010), An adaptive cellular manufacturing system design with routing flexibility and dynamic system reconfiguration, *European Journal of Scientific Research* Vol. 47 No.4, 595-611.

Safei, N., Mehrabad, and M.S., Babakhani, M., (2007), Designing Cellular Manufacturing Systems Under Dynamic and Uncertain Conditions, *Journal Intelligent Manufacturing*, 18:383-399.

Ghezavati, V., and Mehrabad, M.S., (2010), Designing integrated Cellular Manufacturing Systems with scheduling considering stochastic processing time, *International Journal Advanced Manufacturing Technology* 48:707-717.

Khannan, M.S.A, and Maruf, A., (2012a), Pengembangan Model Robust Cellular Manufacturing System Model mempertimbangkan alternatif routing, kapasitas dan perubahan demand, *Prosiding Seminar Sistem Produksi X,* Institut Teknologi Bandung

Khannan, M.S.A, and Maruf, A., (2012b), Development of Robust and Redesigning Cellular Manufacturing System Model Considering Routing Flexibility, Setup Cost and Demand Changes, *Proceedings of 13th Seminar of Asia Pasific Industrial Engineering&Management Systems Conference*, V.Kachitvianukul, H.T.Luong, and R. Pitakaso Eds.

Mahdavi,H.A., Adaei, A., Paydar, M.M., and Soulimanpur, M., (2009), Production Planning and Cell Formation in Dynamic Virtual Cellular Manufacturing Systems with Worker Flexibility, *IEEE*. DOI. 978-11-4244-4136-5/09.

Mahdavi, I., Alaei, A., Paydar, M.M., and Soulimanpour, M. (2010), Designing a mathematical model for dynamic cellular manufacturing systems considering production planning and worker assignment, *Computers and Mathematics with Applications*, volume 60, 1014-1025.

Mohammadi, M., and Forghani, K. (2014) A novel approach for considering layout problem in cellular manufacturing systems with alternative processing routings and subcontracting approach, *Applied Mathematical Modelling* http://dx.doi.org/10.1016/j.apm.2013.11.058.

Negahban, A., and Smith, J.S. (2014) Simulation for manufacturing system design and operation: Literature review and analysis, *Journal of Manufacturing Systems* 33:241-261

Niaki, S.V.D., Mehdizadeh, E., and Tavakolli Moghaddam (2011) A mathematical model for dynamic cellular manufacturing systems with production planning and labor assignment, *POMS 23rd Annual Confrence, Chicago, Illinois*, U.S.A.

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