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Development of Robust and Redesigning Cellular Manufacturing System Model Considering Routing Flexibility, Setup Cost, and Demand Changes

Muhammad Shodiq Abdul Khannan†
Department of Industrial Engineering, Faculty of Engineering
Sarjanawiyata Tamansiswa University, Indonesia
Tel: (+62) 274-562-265 Fax: (+62) 274-547-042
E-mail: mshodiqak@gmail.com

AnasMaruf
Department of Industrial Engineering
Institut Teknologi Bandung, Indonesia
Tel/Fax: (+62) 22-2506449
Email: maruf@ti.itb.ac.id

Abstract. In designing Cellular Manufacturing System (CMS), there are many aspects that require consideration. Among of them are machine capacity, alternative routing process, intra-cell and inter-cell material handling cost and setup cost. Due to these considerations, this study proposes two models: Robust CMS and Redesigning CMS. Both models have the same objective function which is minimizing total cost of the CMS layout design. The total cost consists of machinery depreciation cost, operating costs, inter-cell material handling cost, intra-cell material handling cost, machine relocation costs and setup costs. Robust CMS is a CMS where the machine-cell configuration is fixed during the whole planning period. Redesigning CMS is a CMS where its machine-cell configuration may change during the planning period due to the demand changes. The proposed model for both systems is an integer linear programming model. Numerical examples are elaborated in the paper to depict the influence of changes in demand and total cost.

Keywords: Robust CMS, Redesigning CMS, Routing Flexibility, Setup Cost, demand.

1. INTRODUCTION

Cellular Manufacturing System (CMS) is an application of Group Technology that combines the speed of flow shop and the flexibility of job shop. Beside its benefit, Cellular Manufacturing System design has a low capability to cope with demand changes (Ebara, 2006). In designing CMS, there are many aspects requiring consideration. Among of them are machine capacity, alternative routing process, intra-cell and inter-cell material handling cost and setup cost. Ebara (2006) developed two models in order coping with demand changes: flexible cells that resistance with the changes and redesign cells that adapt and respond to the changes. Flexible CMS, later will be named as Robust CMS, is a CMS where the machine-cell configuration is fixed during the whole planning period. Redesigning CMS is a CMS where its machine-cell configuration may change due to the demand changes during the planning period. Model developed by Ebara (2006) has not considered machine capacity yet. Machine capacity should be considered to ensure that the incoming demand can be processed bythe machine resources. The Objective of this model is to minimize the total material handling cost.

Another parameter facedin real life is an alternativerouting; the production process of a component can be processed on different machines. Jayakumar (2010) developed Redesigning CMS that consider alternative routing process, operating costs, depreciation costs, and material handling cost. This modelhas not consideredsetup cost yet. Setupcostonsome of manufacturingindustryis asignificant cost. Mixed Assembly Lines model (Damayanti, 2007) suggests considering the cost of setup for further research.

†：Corresponding Author

2. LITERATURE REVIEW

Cellular Manufacturing System has been intensively studied in the last three decades. CMS design divides into two strategies: based on similarity coefficient/group technology (Askin, 1997; Shafer, 1993) and machine-cell strategy (Ebara, 2006; Jayakumar, 2010;Javadian, 2011).

There are many design objectives in CMS Design (Garbie, 2008). These objectives are to minimize intra-cell and inter-cell material handling costs (Ebara, 2006), to minimize the machine relocation costs, operating cost, and amortized cost (Jayakumar, 2010), to minimize the machine load variation, to minimize the operating costs, to minimize capital investment, to maximize of resource (machine and labor) utilization, and to maximize the output (Garbie, 2008). Constraint functions considered in CMS design are capacity constraint, routing constraint, and maximum cell size constraint (Jayakumar 2010). Ebara (2006) did not consider capacity contraint in CMS design. In designing CMS, in order coping with demand changes, there are two design categories: Robust CMS (Pillai, 2007) and Redesigning CMS (Jayakumar, 2010). Ebara (2006) developed these two models. In the design of CMS, most cell formation techniques can be separated into two main techniques: mathematical programming (Linear, Programming, Integer Programming and Dynamic Programming) and heuristics approaches (Garbie, 2008). Some models that used mathematical programming are Ebara (2006) and Jayakumar (2010). Tavakoli (2006) used metaheuristic for solving the problem. Javadian (2011) proposed non-dominated sorting genetic algorithm (NSAGAII) as design technique to solve the problem. .

According to the literature review, this study proposes two models: Robust CMS and Redesigning CMS considering Routing Flexibility, Setup Cost, and Demand Changes. This model used Integer Linear Programming to solve the problem.

3. THE MATHEMATICAL MODEL

The Proposed Model is developed mostly based on Ebara (2006) and Jayakumar (2010). This study proposed two models: Robust CMS and Redesigning CMS. The objective function is minimizing the total cost of the CMS layout design. The total cost consists of machinery depreciation cost, operating costs, inter-cell material handling cost, intra-cell material handling cost, machine relocation costs and setup costs.

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 and setup cost are known. Number of machine is fixed during planning periods.

Notation

Index

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

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
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* and *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
F^{inter}	inter-cell material handling cost (robust)
F^{intra}	intra-cell material handling cost(robust)
R^{intra}	intra-cell material handling cost (redesign)
R^{re}	redesign cost including install, shifting and uninstalling (redesign)
$Setup_{pm}$	setup cost for part p { \$/setup}
S_{jpm}	setup cost for individual operation j for part p at machine type m {\$/operation}
UB	maximal cell size i.e., maximum number of machines per cell
D_{ph}	*demand* for part type p at 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)
Tm	time capacity of machine m in terms of unit time (hours) for each period.

Decision variable

Robust CMS

N_{mc}	number of machines of type m assigned to cell c
x_{jpmc}	1, if operation j of part type p is done on machine type m in cell c; 0,

Redesigning CMS

N_{mch}	number of machines of type *m* assigned to cell *c* in period *h*
x_{jpmch}	1, if operation *j* of part type *p* is done on machine type *m* in cell *c* in period h; 0,
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*

Mathematical Formulation

A. Robust CMS

Objective Function

Minimize

$$Z^f = F^{amortized} + F^{operating} + F^{setup} + F^{intra} + F^{inter} \qquad (1)$$

Constraints

$$\sum_{c=1}^{C}\sum_{m=1}^{M} a_{jpm}.x_{jpm} = 1 \qquad \forall j,p \qquad (2)$$

$$\sum_{p=1}^{P}\sum_{j=1}^{Op} D_p.t_{jp}x_{jpmc} \leq T_m N_{mc} \; \forall m,c \qquad (3)$$

$$\sum_{m=1}^{M} N_{mc} \leq UB \qquad \forall m,c \qquad (4)$$

(i). Amortized cost

$$F^{amortized} = H\sum_{c=1}^{C}\sum_{m=1}^{M} N_{mc}C_m^{amor} \qquad (5)$$

(ii). Operating Cost

$$F^{operating} = H\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{O_p}\sum_{m=1}^{M} C^{oper}D_p t_{jpm}x_{jpmc} \qquad (6)$$

(iii). Setup Cost

$$F^{setup} = \sum_{p=1}^{P}\left(\sum_{c=1}^{C}\sum_{m=1}^{M} Setup_{pm}N_{mc} + \sum_{p=1}^{P}\left(\sum_{m=1}^{M}\sum_{j=1}^{O_p} S_{jpm}x_{jpmc}\right)D_p\right) \qquad (7)$$

(iv). Intracell Material Handling Cost

$$F^{intra} = H\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\left\lceil\frac{D_p}{B_p^{intra}}\right\rceil C^{intra}\text{x}\left(\sum_{m=1}^{M}\left|x_{j+1pmc} - x_{jpmc}\right| - \left|\sum_{m=1}^{M} x_{j+1pc} - \sum_{m=1}^{M} x_{jpc}\right|\right) \qquad (8)$$

(v). Intercell Material Handling Cost

$$F^{inter} = H\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\left\lceil\frac{D_{ph}}{B_p^{inter}}\right\rceil C^{inter} \times \left|\sum_{m=1}^{M} x_{(j+1)pmc} - \sum_{m=1}^{M} x_{jpmc}\right| \qquad (9)$$

The objective function of Robust CMS is minimizing total CMS design cost (1) which is consist of amortized cost (5), operating cost (6), setup cost (7), intra-cell material handling cost (8) and inter-cell material handling cost (9). Equation (2) is Routing constraint to ensure each part operation is processed only on one machine among several alternative machines that able to do the process (routing flexibility). Capacity constraint (3) is to ensure machine capacity is not exceeded and to determine the number of each machine type in each cell. Maximum cell size constraint (4) ensures the number of machines allocated to each cell does not exceed the maximum size of the cell.

A. Redesigning CMS

Objective Function

Minimize

$$Z^f = R^{amortized} + R^{operating} + R^{setup} + R^{intra} + R^{inter} + R^{relocation} \qquad (10)$$

Contraints

$$\sum_{c=1}^{C}\sum_{m=1}^{M} a_{jpm}.x_{jpmh} = 1 \qquad \forall j,p,h \qquad (11)$$

$$\sum_{p=1}^{P}\sum_{j=1}^{Op} D_{ph}.t_{jph}x_{jpmch} \leq T_m N_{mch} \; \forall m,c,h \qquad (12)$$

$$\sum_{m=1}^{M} N_{mch} \leq UB \qquad \forall c,h \qquad (13)$$

$$N_{mc(h-1)} + K^{+}_{mch} - K^{-}_{mch}$$

(i). Amortized cost

$$R^{amortized} = \sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{m=1}^{M} N_{mch}C_m^{amor} \qquad (15)$$

(ii). Operating Cost

$$R^{operating} = \sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{j=1}^{O_p}\sum_{m=1}^{M} C_m^{oper}D_{ph}t_{jpm}x_{jpmch} \qquad (16)$$

(iii). Setup Cost

$$R^{setup} = \sum_{p=1}^{P}\left(\sum_{m=1}^{M} Setup_{pm} + \sum_{p=1}^{P}\left(\sum_{m=1}^{M}\sum_{j=1}^{O_p} S_{jpm}x_{jpmc}\right)D_p\right) \qquad (17)$$

(iv). Intracell Material Handling Cost

$$R^{intra} = \frac{1}{2}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\left[\frac{D_p}{B_p^{intra}}\right] C^{intra}\left(\sum_{m=1}^{M}|x_{j+1pmch} - x_{jpmch}| - \left|\sum_{m=1}^{M} x_{j+1pch} - \sum_{m=1}^{M} x_{jpch}\right|\right) \quad (18)$$

(v). Intercell Material Handling Cost

$$R^{inter} = \frac{1}{2}\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{j=1}^{O_p-1}\sum_{c=1}^{C}\left[\frac{D_{ph}}{B_p^{inter}}\right] C^{inter} \times \left|\sum_{m=1}^{M} x_{(j+1)pmch} - \sum_{m=1}^{M} x_{jpmch}\right| \quad (19)$$

(vi). Relocation Cost

$$R^{relocation} = \frac{1}{2}\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{m=1}^{M} C^{re}(K_{mch}^{+} + K_{mch}^{-}) \quad (20)$$

The objective function of Redesigning CMS is minimizing total CMS design cost (14) which consists of amortized cost (15), operating cost (16), setup cost (17), intra-cell material handling cost (18), inter-cell material handling cost (19), and relocation costv(20).

Equation (11) is Routing constraint to ensure each part operation is processed only on one machine among several alternative machines that able to do the process (routing flexibility). Capacity constraint (12) is to ensure machine capacity is not exceeded and to determine the number of each machine type in each cell. Maximum cell size constraint (13) ensures the number of machines allocated to each cell does not exceed the maximum size of the cell. Balance constraint (14) ensures the number of machines is always the same after reconfigurationis conducted.

5. CASE STUDY AND COMPUTATIONAL RESULT

The Numerical Test use the data taken from Jayakumar (2010) which consists of 12 parts and 8 machines with an alternative routing. Data for each part type such as the machine cost, the operating cost per hour, the relocation cost, and the time capacity of each machine provided in Table 1. The units of intercell and intracell material handling costs per batch are considered constant and did not consider the distance travelled. Their values used are \$40 and \$6 respectively. Batch size inter-cell each part type is different around 25 to 45 units/ movement. Batch size intra –cell is different for each part type. Demand for each part type might change during each period. For example demand of part type P1 at period 1 is 400 units, at period 2 is 650 units and period 3 is zero. Redesigning CMS model usethe demand on rolling period h1, h2 and h3 to design the model while Robust CMS used the average demand.

Table 1:Data for Part types.

Part type, *p*	**batch size inter-cell, B^{intra}**	**Inter-cell material handling cost per batch, C^{inter}**	**batch size Intra-cell, B^{intra}**	**Intra-cell material handling cost per batch, C^{intra}**	***Demand* at period, *Dph*,**			**average *Demand*, D_{av}**
					Period 1	Period 2	Period 3	
P1	25	40	5	6	400	650	0	350
P2	30	40	6	6	650	0	400	350
P3	45	40	9	6	0	450	0	150
P4	25	40	5	6	750	500	600	617
P5	35	40	7	6	550	0	750	433
P6	25	40	5	6	0	500	350	283
P7	30	40	6	6	450	0	300	250
P8	25	40	5	6	650	0	350	333
P9	35	40	7	6	750	350	0	367
P10	40	40	8	6	900	450	700	683
P11	35	40	7	6	0	0	700	233
P12	30	40	6	6	350	600	0	317

Table 2: alternative routing data and operating time

Part -*p*	Operation – *j*					
	j=1		*j*=2		*j*=3	
	Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2
1	M7 0.5	M8 0.33	M5 0.94	M7 0.24	M5 0.81	M8 0.45
2	M2 0.28	M5 0.86	M2 0.44	M5 0.76	M3 0.97	M4 0.47
3	M2 0.19	M5 0.74	M4 0.49	M6 0.45	M5 0.65	M7 0.59
4	M1 0.44	M4 0.71	M4 0.36	M8 0.49	M1 0.67	M7 0.51
5	M3 0.48	M6 0.23	M3 0.57	M7 0.24	M2 0.67	M6 0.77
6	M2 0.61	M3 0.63	M2 0.68	M5 0.55	M3 0.88	M4 0.63
7	M1 0.89	M4 0.24	M1 0.81	M6 0.34	M2 0.51	M6 0.71
8	M5 0.58	M6 0.96	M5 0.13	M7 0.36	M3 0.19	M6 0.89
9	M4 0.45	M8 0.67	M3 0.76	M6 0.61	M4 0.35	M5 0.78
10	M3 0.78	M7 0.81	M3 0.47	M6 0.12	M2 0.57	M6 0.48
11	M6 0.39	M8 0.44	M7 0.48	M8 0.72	M7 0.36	M8 0.66
12	M1 0.49	M7 0.67	M1 0.72	M4 0.59	M1 0.33	M8 0.48

Table 3: Data for Machine types

Machine type, *m*	Amortized cost, C^{amor} ($)	Operating Cost, C^{oper}($)	Relocation cost ($)	Machine Capacity, T_m (hour)
M1	1900	6	900	600
M2	1300	8	700	600
M3	1400	7	750	600
M4	1800	6	700	600
M5	1500	6	700	600
M6	1400	7	650	600
M7	1300	8	550	600
M8	1500	9	750	600

Computational Result:

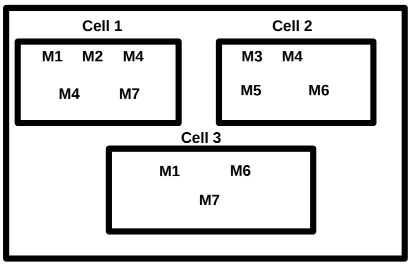


Figure 1: Machine-Cell Configuration Robust CMS

Figure 1 shows the Machine-cell configuration for Robust CMS.Two units of machine types M4, and one unit of machine type M1, M2 and M7 are assigned at Cell 1. One unit of machine type M3, M4, M5 and M6 are assigned at Cell 2. One unit of machine type M1, M6 and M7 are assigned at Cell 3. This configuration is fixed during planning period.

In Table 4, routing operation for each part type *p* are provided. For example, the first and second operations of part type P1 are performed on machine types M7 in cell 1 and the third operation is performed on machine type M5 in Cell 2 ; thus part type P1 needs one inter-cell movement (between cell 1 and cell2). On part type P2, the first and second operations are performed on machine type 2 at Cell 1 therefore there is one intra-cell movement (between machine types M2 and M4 in cell 1). In the similar way, inter-cell movement occurs when batches of part type P3 are moved from cell 1 (where first operation is done on machine type M2 and second operation is done on machine type M4) to cell 3 (where third operation is done on machine type M7).

Table 4: Routing Robust CMS

Part type, *p*	Routing, Machine-Cell
P1	7(1) – 7(1) – 5(2)
P2	2(1) – 2(1) – 4(1)
P3	2(1) – 4(1) – 7(3)
P4	4(1) – 4(1) – 7(1)
P5	6(3) – 7(3) – 2(1)
P6	2(1) – 2(1) – 4(2)
P7	4(2) – 6(3) – 7(3)
P8	5(2) – 5(2) – 3(2)
P9	4(2) – 6(3) – 4(2)
P10	3(2) – 6(3) – 6(2)
P11	6(2) – 7(3) – 7(3)
P12	1(2) – 1(3) – 1(3)

Machine-cell configuration for Robust CMS is shown at figure 2:

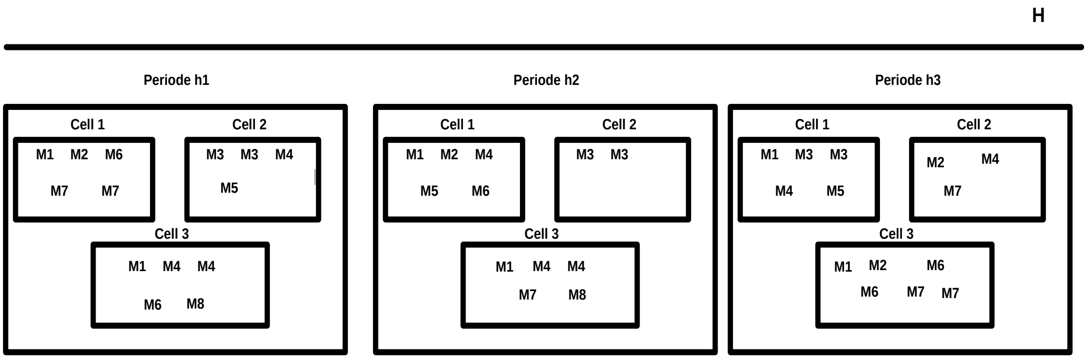


Figure 2: Machine-Cell Configuration Redesigning CMS

Machine-cell configuration for Redesigning CMS at Figure 2 shows that the machine-cell configuration might change during rolling period h1, h2 and h3. At period h1, two units of machine type M7, and one unit of machine type M1, M2 and M6 are assigned at Cell 1. Two unit of machine type M3 and one unit of machine type M4 and M5 are assigned at Cell 2. Two units Machine type M4 and one unit of machine type M1, M6 and M8 are assigned at Cell 3. At period h2, one unit of machine type M1, M2, M4, M5 and M6 are assigned at Cell 1. Two units of machine type M3 are assigned at Cell 2. Two unitsmachine type M4 and One unit of machine type M1, M7 and M8 are assigned at Cell 3. Thus, at period h2 there are different configuration compared to period h1, where at h2 machine type M4 and M5 are assigned to Cell 1. At period h3, two units of machine type M3, and one unit of machine type M1, M4 and M5 are assigned at Cell 1. One unit of machine typesM2, M4 and M7 are assigned at Cell 2. Two-unit machine type M6, M7 and one unit of machine type M1, M2 are assigned at Cell 3. It is proved that Machine-cell configuration for Redesigning CMS might change during rolling period due to the demand changes.

Table 5: Routing Redesigning CMS

Part type	Routing, Machine(Xjpmch)		
	Period 1, *h1*	**Period 2, *h2***	**Period 3, *h3***
P1	8(3) – 7(1) – 8(3)	7(3) – 7(3) – 8(3)	is not produced
P2	6(1) – 2(1) – 4(2)	is not produced	6(3) – 2(2) – 4(2)
P3	is not produced	2(1) – 6(1) – 5(1)	is not produced
P4	1(3) – 3(1) – 1(3)	1(1) – 6(1) – 1(3)	1(3) – 4(1) – 7(2)
P5	6(3) – 7(1) – 6(1)	is not produced	6(3) – 7(3) – 2(3)
P6	is not produced	2(1) – 5(1) – 4(3)	3(1) – 5(1) – 4(1)
P7	4(3) – 6(1) – 2(1)	is not produced	4(2) – 6(3) – 6(3)
P8	5(2) – 5(2) – 3(2)	is not produced	5(1) – 5(1) – 3(1)
P9	4(3) – 6(3) – 4(3)	3(1) – 3(2) – 4(3)	is not produced
P10	3(2) – 6(2) – 6(2)	3(2) – 6(1) – 6(1)	3(1) – 6(3) – 6(3)
P11	is not produced	is not produced	6(3) – 7(3) – 7(3)
P12	1(1) – 1(1) – 1(1)	1(1) – 7(3) – 1(1)	is not produced

In Table 5, routing operation for each part type *p* are provided and are different for each rolling period h1, h2 and h3. For example, at period h1 part type P1, the first operation is performed on machine type M8 in cell 3, the second operation is done on machine type M7 in Cell 1 and third operations of part type P1 is performed on machine types M) in cell 3 and; thus part type P1 needs two inter-cell movements (between cell 3 and cell1). At period h2, Part type P1 all operations are performed in cell 3 with machine type M7, M7 and M8. At period h3, part type P1 is not produced since demand at this period is zero (Table 1). In similar way, at period h1, Part type P2, the first and second operations are performed at Cell 1 (on machine type M6 and M2) and third operation are performed Cell 2 on machine type M4. At period h2 part type P2 is not produced since demand is zero. At period 3, Part type P2 the first operation is performed at Cell 3 on machine type M6 and second operation are performed at Cell 2 with machine type M2 and third operation are performed Cell 2 with machine type M4.

Sensitivity Analysis

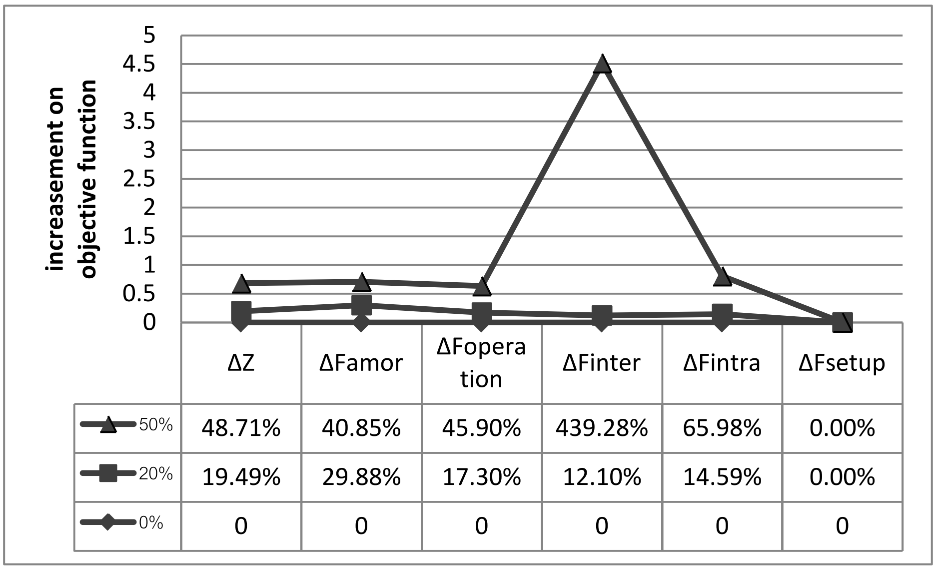
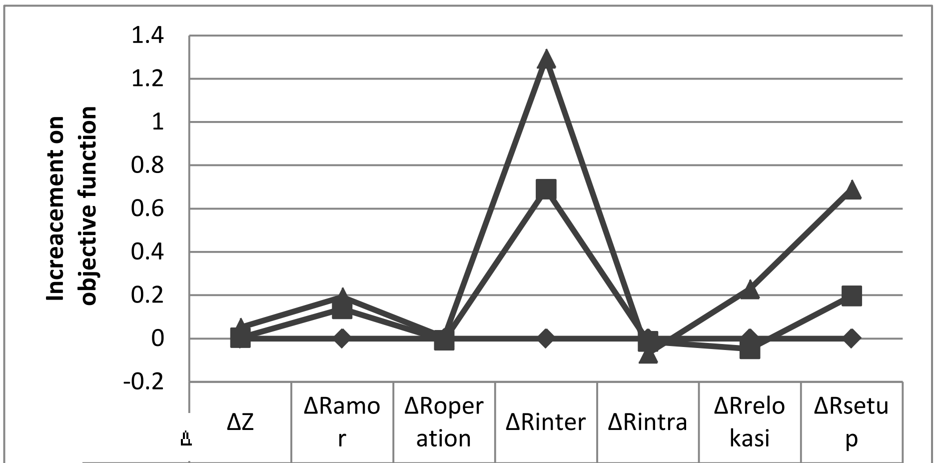


Figure 3: Sensitivity Analysis of Demand Changes on objective function

Sensitivity analysis performed to see the effects of input parameters changes on the objective function. Sensitivity analysis performed for the two input parameters: demand and setup cost. Figure3 shows that there is a change of inter-cell material handling up to 439% when demand is increased by 20%. This is possibly due to capacity shortage so the operations must be processed in a machine outside the cell. Operating costs is linearly rising when demand is increased. Operating cost equals time (t_{jpm}) multiplied by the Demand for each part p (D_p) so that when demand is rising operating costs is rising too. Setup cost is not affected by demand changes because the number of machines used is not changed.



	ΔZ	ΔRamor	ΔRoperation	ΔRinter	ΔRintra	ΔRrelokasi	ΔRsetup
50%	4.72%	5.48%	1.30%	60.44%	-5.53%	27.71%	49.26%
20%	0.37%	13.71%	-0.82%	69.01%	-1.32%	-4.82%	19.70%
0%	0	0	0	0	0	0	0

Figure 4 : Sensitivity Analysis of Setup Parameter Changes to Objective Function

Figure 4 shows that if the setup cost parameter increased by 50%, it will increase inter-cellular material handling cost 60.44%, relocation cost 27.71% and total setup cost 49.26% and decrease intra-cellular material handling cost 5.53%. Meanwhile, if the setup costs parameter increased by 20% , it will increase inter-cellular material handling 69.01% and decrease inter-cellular material handling cost 1.32% while total setup cost increased by19.70%. The increase in setup cost parameter (Δsetup) tends to increase the setup cost (ΔRsetup) linearly, material handling cost (ΔRintra) decrease and Inter-cell material handling cost (ΔRinter) increase. This means the jobs for processing demand mostly performed inter-cell.

5. CONCLUSION

In this study, two models, Robust and Redesigning Cellular Manufacturing System were developed. Both models consider the setup cost, machine capacity and demand changes. The results show that the setup cost should be considered in Cellular Manufacturing System design because it made a different machine configuration. In other words, CMS configuration is case sensitive to the changes of the setup cost. Robust CMS best for non-fluctuating demand and Redesigning CMS best for fluctuating demand.

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AUTHOR BIOGRAPHIES

Muhammad Shodiq Abdul Khannan is a lecturer in Department of Industrial Engineering, Faculty of Engineering Sarjanawiyata Tamansiswa University, Yogyakarta, Indonesia. He received a Master of Industrial Engineering, at Bandung Institute of Technology in2012. His research interests include Cellular Manufacturing System and Collaborative Production Planning. His email address is <mshodiqak@gmail.com>

AnasMa'ruf received doctor degree in Mechanical and Structural Engineering from Toyohashi University of Technology, Japan, in 2000. Since 2007 he is Associate Professor at the Manufacturing System Research Group, Faculty of Industrial Technology, InstitutTeknologi Bandung. His research interest is in the field of CAD/CAM, intelligent manufacturing system and production planning and control for MTO industry. His email address is <maruf@ti.itb.ac.id>