MANUFACTURING CELL LAYOUT DESIGN CONSIDERING DYNAMIC CONDITIONS AND INVENTORY

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ABSTRACT: *The Cellular Manufacturing is adopted nowadays in batch type manufacturing industry for its production with increased productivity, less cost and time with effective control. The proposed optimization model is used to determine the cost of machine cells, i.e., machine duplication, part subcontract, inter intra cellular movements cost and cost of production associated with machine cell, such as machine reconfiguration and part inventory considering machine flexibility for various time periods. A linear programming integer model is proposed to calculate the cellular manufacturing production and associated costs for the changes in time period, part type and volume considering machine flexibility. The manufacturing data in the incidence matrix and machine cell, part family data in the block diagonal form are given as input to the optimization programming language Ilog Cplex and the output are given for the proposed mathematical model. The data related to machine duplication, part subcontract, inter intra cellular movement; machine reconfiguration and part inventory are given. Two dimensional shop floor layouts are presented in rectilinear coordinates for all the problems for easy analysis of material movement length and shop floor area*

KEYWORDS*: Cell layout design, Exceptional elements, Machine duplication, Machine flexibility, Part type and demand, Part subcontract.*

1 INTRODUCTION

In a Cellular Manufacturing System (CMS), identical components are grouped as families and related machines are formed as cells so that one part family can be manufactured within a machine cell. Machine-cell formation is to bring dissimilar machines together and dedicate them to the manufacture of one or more part families in manufacturing industries. The types of components, which require to be processed in more than one cell, are known as exceptional components or bottleneck components. The operations carried outside the cell are known as exceptional elements. A machine associated with the processing of many exceptional components is known as a bottleneck machine.

If machine flexibility is taken into consideration, maximum of exceptional elements can be possibly reduced. One or more operations are performed by a single machine; this machine has flexibility which can process the exceptional component in the cell where it is assigned. If dynamic conditions such as part type and volume changes are considered over the period, the machine cells and part families are also changing with the effect of attributes of manufacturing environment. Reconfiguration is removing the existing machines from machine cells, called machine relocation, adding new machines to cells including machine duplication.

It is usually found necessary to maintain inventories of raw materials, work-in process goods and finished goods. A manufacturing industry do inventory because the resources are more costly or less profitable. Materials Requirement Planning (MRP) attempts to maintain the alignment between the order due date and the order need date. Production Planning (PP) means the usage of manufacturing facilities in various successive time periods with the aim of optimizing the production costs.

The proposed optimization models are given with the constraints for finding machine multi capacity to carry out the operations of exceptional element to mainly reduce machine duplication. Another proposed model is used to find machine reconfiguration and part inventory over the given time periods and to cope with the changes in part variety and volume. The cell layout will have work cells inside which machine tools are arranged in series or cross lines or U shape as per process plans.

1.1 Objectives

To reform machine cells and part families with and without considering machine flexibility,

To optimize costs of exceptional elements and production such as machine duplication, parts subcontract, inter cellular movement, intra cellular movement, machine reconfiguration and parts inventory considering the machine flexibility in dynamic manufacturing conditions such as changes in time, part demands and varieties,

In this paper, in section 2, literature review about various costs optimization models related to manufacturing cell operating cost optimization is given compared to the models of the recent and last decades. In section 3, a novel cost optimization model is proposed for finding the cost of production in manufacturing cell for successive time periods including exceptional elements, reconfiguration and inventory over cost reduction literatures given in recent times.

2 LITERATURE REVIEW

This section of the review is aimed to evaluate the elimination of costs directly and indirectly related to exceptional elements. A bi-objective possibilistic nonlinear mixed-integer programming model was presented in uncertain situations to have a suitable CMS with the aim of minimizing the total costs and total inaction of workers and machines, simultaneously. In this context, the demand for each product with a specific quality level and linguistic parameters such as product quality level, worker's skill level, and job hardness level on machines were considered with fuzzy logics, (Hashemoghli et al. 2019). A two-stage stochastic programming approach was followed to consider the uncertainty and to generate the problem. The objective function was to minimize the summation of production, subcontracting, material handling, and machine idleness costs. The model was considering simultaneous multiple routings and subcontracting. (Mahootchia et al. 2018). The objective function was minimizing total expected cost consisting of 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 determined optimum cell formation and optimum lot size (Khannan et al. 2016). The proposed model was decreasing the material handling cost and also increasing the machine used in a cell (Tamal Ghosh et al. 2014). A nonlinear programming model was proposed in significant dynamic conditions which reduce the cost of the estimated demands for inter/intracellular movements of elements (forward and backward movements), the presence of exceptional elements, intercellular dislocation of machines, and cellular reconfiguration and operational costs and initial cost of the machinery (Amir et al. 2018). The fuzzy multi-objective parametric programming is used to minimize the cost of exceptional element elimination, to minimize the number of outer cell operations, and to maximize utilized machine capacity (Arikan & Gungor 2005). This paper processed the problem of designing cellular manufacturing systems incorporating several design features including multi-period production planning, sequence of operations, alternate process routings, intra-cell layout, dynamic system reconfiguration, duplicate machines, machine capacity, lot splitting, and material flow between machines in a dynamic environment(Mohammad Mahdi Paydar et al., 2013). An integrated mathematical model of the multi-period cell formation in a dynamic cellular manufacturing system (DCMS) is proposed with the aim of getting the optimal cost for it (Narendra Mohan., Srinivasa Rao, 2014) The above review on recent methodologies yielded that cost elimination of EE must look into intra cell movements and intercell movements significantly by correlating machine duplication and part subcontract respectively and for changes in part type and volume, it have to consider the machine reconfiguration and part inventory over different planning horizon and machine flexibility for eliminating exceptional machines

3 MATHEMATICAL MODEL FORMULATION CONSIDERING MACHINE FLEXIBILITY

3.1. Assumptions for optimization model and layout design

The proposed model is considering multi-period production planning, machine flexibility, inter cell movement, intra-cell movement and cell reconfiguration along with alternative processes routings.

The manufacturing system is considering production in a number of time periods. One time period could be a week, a month, a season, or a year. The manufacturing time of operations for alternative process plans are acquired as input data. One or more job sequences of all operations for all part types over machines are known. The current, future demands, and batch sizes of parts are known for fixed periodic intervals, and no. of batches are also calculated. The purchase price and the duplication budget are known for all machine types. Subcontract price; inter-cell and intra cell movement costs are known for all parts by considering that parts are moved between the cells and in the cells, in batches. Parts are subcontracted as a whole equal to demand to carry out one or more operations and not as a finished part. The entire demand of each part has to be completed in the manufacturing within the period and the quantity of production is pre-deterministic with respect to demand, processing time and production volume. Some machines can process one or more operations (i.e., machine flexibility). Likewise, each operation can be done by one or more machine types at different times. Parts are moved between and within cells. Inter-cell movement is incurred whenever consecutive operations of the same part type are carried out in different cells. The intra-cell movement is incurred whenever consecutive operations of the same part type are processed in the same cell.

3.2 Mathematical linear programming cost optimization model

The objective of the proposed linear programming model is the reduction of the EE costs. The inferences from literature review are the costs of EE because of inter intra movements; duplication and subcontract are most of recent crisis in the manufacturing sector. If only duplication is the remedy for an exceptional element, then there will be no intercellular movements, hence it is the need to include intracellular movements in objective function as the proposal in this work over the cost's elimination given by (Arikan & Gungor 2005). The proposal in this model is the inclusion of the budget constraint to set the limit for the machine duplication. The other proposal is considering multi-capacity of machines. If a machine can perform more than one operation, this machine multi-capacity or machine flexibility is used to reduce the exceptional element, particularly used to eliminate the machine duplication of bottleneck machines.

In the analysis of cost of cell formation, apart from exceptional elements, reconfiguration and inventory are taking vital role in various time periods with changes in part demand and variety. Machine Reconfiguration and parts inventory are considered important in CMS because the manufacturing is carried out along with the time phase for changes in parts varieties and volume. In dynamic conditions, during various successive time periods, machines are relocated as reconfiguration and changes in part demand should be managed as part inventory.

Inventory uses Material requirement planning (MRP) for a system of planning and scheduling the time phase material requirements to release materials and receive materials that enable the production schedule to be executed. Thus, the master production schedule is the driving force for MRP. It provides information such as due dates for components that are subsequently used for shop floor control. Once this information is available, it enables managers to estimate the detailed requirements for each work centres.

Decision variables

Zijk - Number of intercell movements required by part j when machine i not available in cell k,

Wijk - Number of intra-cell movements required by part j w.r.t to machine i in cells(s) k,

Oijk - Number of units of part j to be subcontracted when machine i not available in cell k,

Mijk- No. of machine i dedicated by duplication to cell k for producing exceptional part j.

In addition to EE costs decision variables mentioned earlier, decision variables for machines adding and removing to and from cells and part inventory are,

N+ik (t) = No. of machine type i added to cell k in period t

N-ik (t) = No. of machine type i removed from cell k in period t

Ivj (t) = Inventory quantity of part type j kept in the period t and carried to period t+1

Step 1: The objective function is to maximize the sum of the savings by either on duplicating the exceptional machines or subcontracting the exceptional parts in the original cell.

The objective function is to maximize the savings by,

Minimizing

$$\sum_t^T \sum_k^c \sum_i^M \sum_j^C (\mathbf{A_i}.\mathbf{M_{ijk}}) + \sum_t^T \sum_k^c \sum_i^M \sum_j^C (\mathbf{I_j}\,\mathbf{Z_{ijk}}\mathbf{Bs_j}) + \sum_t^T \sum_k^c \sum_i^M \sum_j^C (\mathbf{S_j}\mathbf{O_{ijk}}\mathbf{D_j}) + \sum_t^T \sum_k^c \sum_i^M \sum_j^C (\mathbf{IA_i}\mathbf{W_{ijk}}\mathbf{Bs_j}) + \frac{1}{2}\sum_t^T \sum_k^c \sum_i^M \sum_j^C [\,RC_i\,(\mathbf{N^+_{ik}(t)} + \mathbf{N^-_{ik}(t)})] + \sum_t^T \sum_k^c \sum_i^M \sum_j^C (\mathbf{h_j}\mathbf{Iv_j(t)}) \quad (1)$$

Equation (1) is an objective function that is to minimize machine duplication cost, intercellular movement cost, parts subcontracting cost, and intra-cellular movement cost cell reconfiguration cost and inventory cost.

Step 2: The constraints for bottleneck machines, machine flexibility, intra-cell movements, and bottleneck parts concerning subcontract as well as intercell movements originally assigned to the same cell are,

$$\text{Xik} - \text{Yjk} + \text{Uijk} - \text{Vijk} = 0 \qquad \forall i,j,k \qquad (2)$$

$$\sum_k^c \sum_i^M \sum_j^C MTij\ x\ Dj \le Ci \qquad \forall i,j,k \qquad (3)$$

$$\sum_i^M \sum_j^C \text{Mijk} \le \text{Rik} \qquad \forall i,j,k \qquad (4)$$

$$\sum_i^M \sum_j^C Ci\ /(MTij\ XDj)\ \ge Qi \qquad \forall i,j \qquad (5)$$

$$\sum_k^c \sum_i^M \sum_j^C Mijk\ x\ MTij\ x\ Dj \le Ci \qquad \forall i,j,k \qquad (6)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if(Xik = 1\ \&\&\ Yjk = 0\&\&Inc = 1) \\ Uijk = 1, Vijk = Wijk = 0; \end{matrix} \qquad \forall i,j,k \qquad (7)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if(Xik = 0\ \&\&\ Yjk = 1\ \&\&Inc = 1) \\ Vijk = Wijk = 1,\ Uijk = 0; \end{matrix} \qquad \forall i,j,k \qquad (8)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if(Xik = 1\ \&\&\ Yjk = 1\ ) \\ Wijk = 1; \end{matrix} \qquad \forall i,j,k \qquad (9)$$

$$\sum_k^c \sum_{i,a}^M \sum_{j,b}^C \begin{matrix} if\ (MFabk == Seqijk) \\ Uijk = 0,\ \ Wabk = 1; \end{matrix} \qquad \forall i,j,k,a,b \qquad (10)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if(Uijk = 1\ \&\&\ Xjk = 1\ \&\&Bik \le (Djk * Sjk * 52 * 5)) \\ Mijk = 1,\ Oijk = 0, Zijk = 0; \end{matrix} \qquad (11)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if\big(Vijk = 1\ \&\&\ Yjk = 1\ \&\&Bik > (Djk * Sjk * 52 * 5)\big) \\ Oijk = 1, Zijk = 1, Mijk = 0\ ; \end{matrix} \qquad (12)$$

$$\sum_k^c \sum_i^M \sum_j^C Mijk\ X\ Ai\ \le Bik \qquad \forall i,j,k \qquad (13)$$

The **constraints** for machine cell reconfiguration and part inventory w.r.t. time periods are,

$$N_{ik}\ (t\text{-}1) + N_{ik}^{+}\ (t) - N_{ik}^{-}(t) = N_{ik}\ (t), \quad \forall\ i, k, t \qquad (14)$$

$$Iv_{jt} = Iv_{j\ (t\text{-}1)} + PQ_{jt} - D_{jt} \qquad \forall\ j, t \qquad (15)$$

$$Iv_{jt}^{+} \le Iv_{jt},\ Iv_{jt}^{-} \ge -Iv_{jt},\ Iv_{jt} = 0 \qquad \forall\ j, t \qquad (16)$$

$$\text{Xik, Yjk, Uijk, Vijk, INijk, DNijk, SCijk} = 0 \text{ or} 1 \qquad (17)$$

$$\text{Rik, Qi} = \text{ integer} \qquad (18)$$

Equation (2) is ensuring each machine and component is assigned in one cell only. Equation (3) ensures that the sum of machining times of operations in each machine is within the capacity. Equation (4) is to check that machines to be duplicated in each cell to process the part are less than the total number of duplicated machines of the same type in the cell. Equation (5) is to ensure a number of each machine type is within its utilization capacity otherwise its number will increase. Equation (6) is to ensure that the sum of machining times of operations in duplicated machines of various parts in a cell is less than its capacity. Equation (7) and Equation (8) are stating conditions to assign values for Uijk and Vijk as 0 or 1 as well as Wijk as 0. Equation (9) is the condition to assign Wijk as 1. Equation (10) is for ensuring any machine flexibility (multi-capacity) for same job sequence of bottleneck machine and to assign the value to INijk and Uijk. Equations 11, 12 are assigning 0 or 1 to Mijk, Zijk and Oijk. Equation 13 is setting upper limit, budget for duplicating machine in each cell.

Equation (14) is called as an equilibrium constraint ensuring that the number of machines in the current period is equal to the number of machines in the previous period, plus the number of machines being installed, and minus the number of machines being uninstalled. Equation (15) indicates the equilibrium inventory constraint between periods for each part type at each period. Equation (16) determines the inventory and backorder level of each part type at each period. Obviously, the total demand of all part types over the horizon planning must be satisfied during the horizon planning.

The machine flexibility is given as job sequence similar to the part incidences mentioned in single quote. Reconfiguration cost which is almost equal in both installation and uninstallation of machines is given for each machine type. Inventory cost which includes inventory, carrying and ordering is given for each component as input.

3.3 Input Data

The incidence matrix of size M x N is the primary data input given as Inc [i][j](Refer Table 5). Manufacturing Time MT[i][j], Machine Flexibility MF[i][j], Job sequence Seq[i][j] are also given. Block diagonal form is considered for input as machine cell X [i][k] and part family Y [j][k] in terms of 0 and 1(Refer figure 1) in such a way that chosen machine/part is falling in a particular machine cell/part family, it is taken as 1, 0 otherwise. The purchase price, machine duplication budget, the capacity of each machine type are given as A[i], B[i], C[i]. Intercell moving cost, intra cell moving cost, subcontract price, part, present and future demands, and production volume of each part type are given as I[j], IA[j], S[j], D[j], D1[j] and V[j]. (Refer Table 3.23).

Step 3: If an exceptional part is assigned to two or more exceptional machines, then either all of these machines or none are duplicated in the cell to which the part was originally assigned.

Step 4: The constraint for duplication budget is formulated using procure cost associated for those machines related to each bottleneck part.

3.4 Numerical Illustration

The bench mark problem is solved to find out the costs of duplication, subcontract, and intra, inter cellular movements, reconfiguration and inventory with considering the machine flexibility for the past time period t1 and current time period t2 for bench mark problem of moderate in size given in machine component incidence matrices.

By using the cell formation similarity coefficient matrix heuristic approach (Ramesh et al, 2014), the machine cells and part families are formed and given in block diagonal form. The part incidence matrix with manufacturing data, costs and machine flexibility and the block diagonal form are used as input data for the optimization model.

Benchmark problem: 7 machines – 11 components

Table 1 7 machines – 11 components Part incidence matrix

	1		2		3		4		5		6		7		8		9		10		11					
M / C	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	t1	t2	A_i	B_i	Rci	C_i
1	0	1(3)	2(4)	0	3(1)	0	0	0	2(1)	2(1)	0	0	0	0	2(1)	0	2(1)	2(1)	0	0	0	2(1)	75000	150000	3000	5200
2	0	0	1(2)	0	1(2)	0	0	0	1(5)	0	0	2(1)	0	0	3(1)	0	3(1)	0	0	2(1)	0	1(3)	60000	120000	2000	5400
3	2(3)	0	0	0	0	1(4)	1(3)	0	0	0	3(1)	1(3)	0	0	0	0	0	0	1(3)	1(3)	0	0	120000	240000	8000	5400
4	1(2)	0	0	2(1)	0	0	3(1)	0	0	0	1(4)	0	0	1(3)	0	1(4)	0	0	0	0	0	0	80000	160000	3200	5400
5	0	0	0	0	0	0	2(4)	0	0	1(3)	0	0	1(3)	0	0	1'(4)	0	1(3)	2(5)	0	1(5)	0	80000	160000	3300	5200
6	0	2(4)	0	0	2(5)	0	0	0	0	0	0	0	2(1)	0	0	2(1)	0	3(1)	3(2)	0	2(4)	0	50000	100000	1800	5400
7	0	0	3(1)	1(3)	0	0	0	1(3)	3(1)	0	0	0	0	2(1)	1(5)	0	1(2)	0	0	0	0	0	40000	80000	1600	5400
I_J	4		3		5		7		2		3		4		3		4		2		5					
IA_j	3		6		4		5		2		3		2		4		5		3		2					
S_j	6		5		8		7		6		7		9		6		5		8		6					
hj	8		7		8		8		7		9		7		7		8		7		8					
Dj	330	300	210	240	350	350	210	360	360	320	250	280	350	400	250	240	300	250	420	320	360	300				
Vj	60		50		70		70		60		50		70		50		50		70		60					

(Input source Hachicha et al, 2007)

7 X 11

M/C	2	3	5	8	9	1	4	6	7	10	11
1	1	1	1	1	1						
2	1	1	1	1	1						
7	1	1'	1	1	1						
3						1	1	1		1	
4						1	1	1			
5							1		1	1	1
6		1							1	1	1

Fig 1 Block diagonal form for past time period t=1

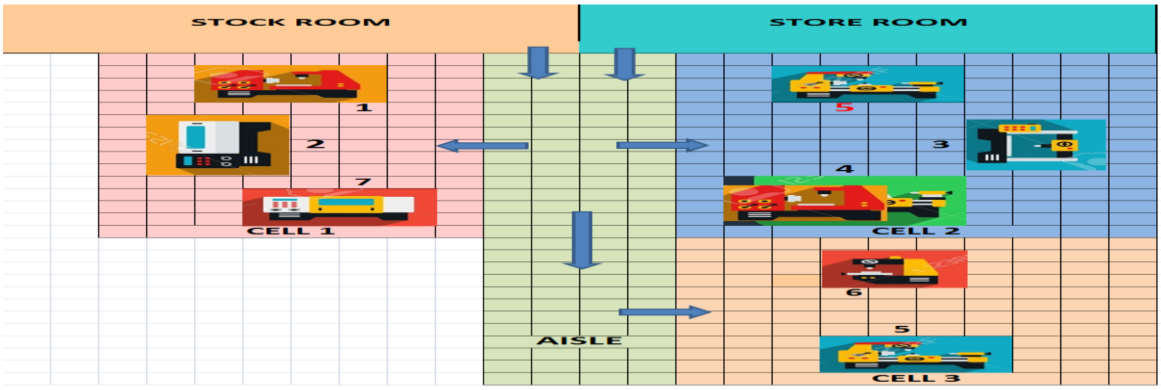

Fig 2 Two dimensional rectilinear layouts for past time period t=1

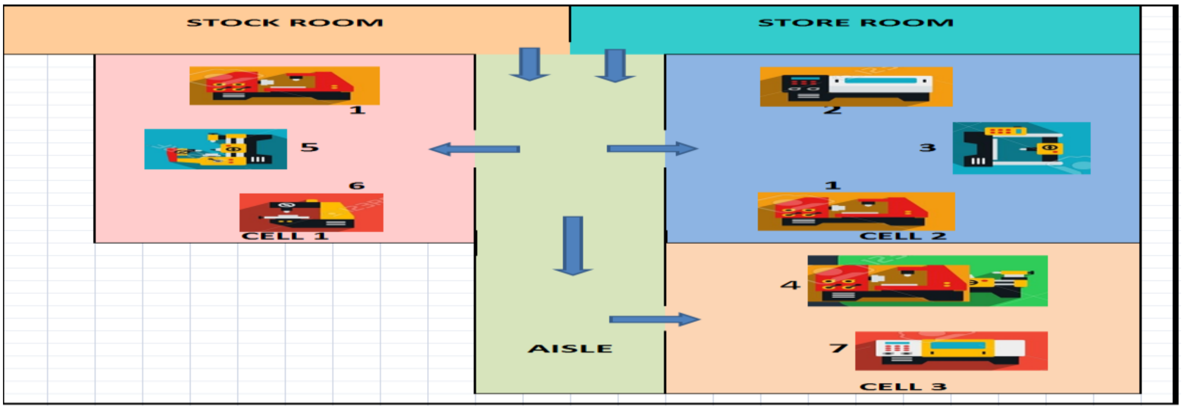

Fig 3 Two dimensional rectilinear layouts for current period t=2

3.4.1 Optimization model CPLEX OPL output for past and current time periods t1, t2

Production plan with inventory for periods 1 and 2.

Table 2 Bench mark problem 7machinesX11components:

Quantity wrt period	**Time Period t1**										
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**
PQjt1	360	200	420	350	360	300	350	250	250	350	300
Ijt-1	0	50	0	20	0	0	40	0	0	0	0
Ijt1	60	10	70	-10	40	20	-10	10	0	30	0
Djt1	300	240	350	360	320	280	400	240	250	320	300
Quantity wrt period	Time Period t2										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
PQjt2	300	200	350	280	300	250	420	250	300	420	360
Ijt1	60	10	70	-10	40	20	-10	10	0	30	0
Ijt2	30	0	0	60	-20	20	60	10	0	30	0
Djt2	330	210	420	210	360	250	350	250	300	420	360

Table 3 Optimal Solution for DCMS for Bench mark problem 3 7machinesX11components

Total Cost	**Machine Duplication Cost $A_i . M_{ijk}$**	**Parts Subcontract cost $S_j O_{ijk} D_j$**	**Intercell Movement cost $I_j Z_{ijk} Bs_j$**	**Intracell Movement cost $IA_i W_{ijk} BS_j$**
₹99045	₹80000	₹2640	₹50	₹1175

Reconfigure Machines removed $\mathbf{N}_{\mathbf{ik}}^{-}(\mathbf{t})$	Reconfigure Machines added $\mathbf{N}_{\mathbf{ik}}^{+}(\mathbf{t})$	Machine Reconfig. cost $RC_i\left(\mathbf{N}_{\mathbf{ik}}^{+}(\mathbf{t})+\mathbf{N}_{\mathbf{ik}}^{-}(\mathbf{t})\right)$	Part Inventory $\mathbf{Iv_j}(\mathbf{t})$	Part Inventory cost $\mathbf{h_j Iv_j}(\mathbf{t})$
Cell1 – 2, 7 Cell 2 – 4 Cell 3 – 5, 6	Cell 1 – 5, 6 Cell 2 – 2 Cell 3 – 4, 7	₹11900	410Nos.	₹3280

3.5 Discussion of results

In bench mark problem, each cell requires reconfiguration such as machine installation and uninstallation and also part inventory is required in both the time periods. Machine duplication consumes much of total cost apart from another part subcontract. In all the cases, total part inventory are given in the table, part subcontract are given for the entire demand and movement cost are given for number of batches.

4 CONCLUSION

The proposed mathematical model is used to reduce most of the exceptional elements by considering the machine flexibility. This multi capacity of machines helped in reducing the machine cell cost by avoiding the duplication of bottleneck machines. Another proposed optimization model for machine cell multi period production cost is used to reveal effectively the machine reconfiguration and part inventory data which are helpful in production plan of regular manufacturing activities in a lean cell manufacturing. The shop floor layouts are used to determine the material movement length, floor area which is helping in setting up cell layout with the capability of easy reconfiguration with respect to changes in part type and volume as well as various time periods. The optimization models can be extended for line balancing, scheduling and inbound supply chain for setting up of facility cell layouts for different cellular manufacturing.

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