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Economic Tradeoff Optimization Model for Machine Cell Layout Design

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Keywords: exceptional elements, parts subcontract, machine duplication, cell layout design.

ABSTRACT

This proposed work is used to optimize costs of exceptional elements of machine cells for a variety of components in changing environment to have reduced material movements in cell layout. The exceptional elements are eliminated in the optimization model by doing machine duplication and part subcontract. Then the shop floor layout is designed to have optimized material movements between cells and within a cell. The result of a linear programming optimization model is cost savings, machines duplicated, parts subcontracted, inter intracellular movements. Finally, the output of inbound facility design is the floor layout which has machine cell clusters with optimized floor areas. The optimization model is provided with budgetary constraint for duplication and economic tradeoff between machine duplication and part subcontract. Cell layout is prepared to reveal the saving in floor area and material movement lengths than in process layout with the help of distance matrix and dimensions of cells.

INTRODUCTION

Nowadays, batch type manufacturing industries are facing difficulty from the increasingly aggressive global market environment. Low product life-cycles, lead time and wide customer demands are the targets to the manufacturers to improve the efficiency and productivity of their production activities. In order to cope with these, Cellular Manufacturing System (CMS) is implemented because of its benefits such as reduction in setup time, small batch sizes, inventory control of work-in-process and finished components, less material handling costs and time, reduced throughput time, less requirements of tools and accessories, less space required, good product quality, better overall control of operations.

In a CMS system, similar components are grouped as families and related machines are formed as cells in order that one part family can be manufactured within a machine cell. The machine cell formation has Exceptional Elements (EE), i.e., unassigned machines and parts and Void Elements (VE). EE induces interactions between two manufacturing cells and VE i.e., elements with no operations inside block diagonals which affect machine utilization and grouping efficiency. An exceptional component is considered as a component that requires manufacturing on machines in two or more cells. An exceptional machine manufactures parts from two or more part families. Exceptional elements create intracellular movements which affect the independence of the cells and increase costs.

The cell layout will have work cells in which machine tools are arranged in series or cross lines as per process plans of parts. But U-shaped layout can be preferred in the cell design which will have simultaneous in-line or cross movements of materials.

LITERATURE REVIEW

The review has been conducted over the recent literatures of mathematical approaches. This section of review is aimed to evaluate the elimination of costs directly related to the exceptional elements. Parametric programming by Arikan and Gungor (2005) is used to reduce the cost of an exceptional element, to decrease a number of outer cell operations and to increase utilized machine capacity. The modified genetic algorithm by Zlatan & Tonci (2006) in interchanging block diagonal form is for reducing voids inside cells and exceptional elements outside cells. Two alternative actions are evaluated by Hachicha et al., (2007) and a bottleneck machine can be duplicated, or it may be allowed and manufacturing parameters are incorporated into the proposed simulation study

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such as a job sequence; batch size and setup time in comparing the cost of alternatives. The model is proposed by Iraj Mahdavi (2008) with a model which considers reducing the cost of to and fro movements between cells and within the cells and the investment cost of machines. The model by Chang-Chun and Chung-Ying (2010) proposed to reduce the number of movements between cells, voids and EEs, minimizes the total cost of duplicated machines without considering processing time of operations. The above review yielded that cost elimination of EE must look into intra cell movements and intercell movements significantly by correlating machine duplication and part subcontract respectively. A systematic methodology was developed by Wai-Tien et al., (2016) to combine the same machines in the cell which is simulated and the outcome of the cell design is evaluated by analysis of variance. Elwyn John et al., (2010) proposed weighted similarity coefficient technique which deals production cell design and also incorporated method to give the best performance at low costs in the design of manufacturing facilities. Alan Davies et al., (2013) presented a design methodology which aimed to decrease work part movement, thereby providing a faster throughput time and lower production costs for companies who use cellular manufacturing systems in their production operations. Petrillo et al., (2016) provided a layout which made use of the available space, easy transfer of material between the various sections of the shop floor and ensure a smooth flow and the proximity between units with a close relationship to each other.

Objectives

In this proposed work, in the section 2, a linear programming model is developed to reduce the cost of exceptional elements aroused in machine cell formation by determining the duplication and the subcontract and it is benchmarked over cost reduction given in [1]. Machine cell formation is done by the same authors in previous literatures and the inputs for the three Bench mark problems for optimization model are taken from those literatures. In section 3, material movement lengths, the sizes of cells, positioning cells as well as machines are determined with the help of the sort of cells and machines with respect to the origin and finally a 2D shop floor layout is designed.

OPTIMIZATION MODEL

The selected benchmark problems (literature references of five mathematical approaches and one metaheuristic approach of different sizes are mentioned in each input Bench mark problem) of small, moderate in size, in machine component incidence matrices are solved; machine cells and part families are formed using PARI algorithm is given in literature (Ramesh et al., 2014). In this paper, Bench mark problem 2 is shown with the block diagonal output to validate the proposed approach.

Bench mark problem 1: 7machinesX 8 Components. (Input Data from (Murugan, Selladurai, 2007))

Bench mark problem2: 10 Machines X 8 Components Cells, part families are formed after 4 iterations in spreadsheet simulation. After weighting based approach used in series in such a way that cells then part families are refined and to have perfect clusters because parts are less than the machines. In this solution, void is only one and EEs are 4 as in the Table 2.

Table1: Incidence matrix with production data. (Input Data from (Zlatan, Tonci, 2006))

M/P	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Ai**	**Ci**	**Bi**
1	3(4)				1(3)	1(5)		1(4)	450000	5400	900000
2			3(5)				1(3)		40000	5400	80000
3	2(6)					4(4)		3(3)	800000	5400	1600000
4		1(3)		1(3)					650000	5400	1300000
5		2(4)		3(4)	3(5)				750000	5400	1500000
6			4(4)				3(2)	5(6)	700000	5400	1400000
7	4(3)		2(3)			2(3)		4(3)	610000	5400	1220000
8			1(2)				2(5)		420000	5400	840000
9	1(4)				2(3)	3(4)		2(3)	380000	5400	760000
10		3(5)		2(3)	4(4)				260000	5400	520000
Si	3.5	3.75	3.5	3.25	4.0	4.25	3.75	3.50			
Ii	4.0	4.5	3.5	4.5	4.0	5.0	3.5	4.0			
IAi	4.25	5.0	4.5	5.0	4.5	5.0	4.0	4.5			
Di	275	300	280	335	300	350	350	250			
Vi	35	30	35	40	35	35	35	30			

Table2: Block diagonal form

M/P	1	6	8	7	3	2	4	5
1	1	1	1					1
3	1	1	1					
7	1	1	1		1			
9	1	-1	1					1
2				1	1			
8				1	1			
6	1			1	1			
10						1	1	1
5						1	1	1
4						1	1	

Authors have worked out for machine cell formation and its output in block diagonal form is taken for input to this optimization model.

*Bench mark problem 3: 9Machines X 10 Components (*Input data from Arikan, Gungor, 2005)
*Bench mark problem 4:10Machines X 12Components (*Input Data from Chalapathi, 2012)
*Bench mark problem 5:10Machines X 20Components (*Input data from Iraj Mahdavi et. al, 2008)
*Bench mark problem 6:18Machines X 24Components (*Input data from Fauwzi et. al, 2008)

The aim of the proposed linear programming model is considered as the reduction of the EE costs. The inferences from literature review are the costs of EE such as inter intra movements; duplication and subcontract are mostly of the 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 the objective function as the proposal in this work over the cost's elimination given by Arikan, Gungor, 2005. The other proposal in this model is the inclusion of the budget constraint to set the limit for the machine duplication.

Decision variables

Z_{ijk} - Number of intercell movements required by part j when a machine i not available in cell k,

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

O_{ijk} - Number of units of part j to be subcontracted when a machine I not available in cell k,

M_{ijk} - No. of machine i dedicated by duplication to cell k for producing exceptional part j.

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

$$\sum_k^c \sum_i^M \sum_j^C (Ai, Mijk) + \sum_k^c \sum_i^M \sum_j^C (Ij, Zijk, Dj) + \sum_k^c \sum_i^M \sum_j^C (Sj, Oijk, Dj) + \sum_k^c \sum_i^M \sum_j^C (IAi, Wijk, Dj) \quad (1)$$

Equation 1 is an objective function which is to minimize machine duplication cost, intercellular movement cost, parts subcontracting cost and intracellular movement cost.

The constraints for bottleneck machines, intra cell movements and bottleneck parts with respect to subcontract as well as inter cell movements originally assigned to the same cell are,

$$X_{ik} - Y_{jk} + U_{ijk} - V_{ijk} = 0 \quad (2)$$

$$\sum_k^c \sum_i^M \sum_j^C MTij \; x \; Dj \le Ci \quad (3)$$

$$\sum_i^M \sum_j^C \text{Mijk} \le \text{Rik} \quad (4)$$

$$C_i / (MT_{ij} \text{ x } D_j) \ge Q_i \quad (5)$$

$$\sum_k^c \sum_i^M \sum_j^C Mijk \; x \; MTij \; x \; Dj \le Ci \quad (6)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if\ (Xik = 1 \;\&\&\; Yjk = 0) \\ Uijk = 1; Vijk = Wijk = 0; \end{matrix} \quad (7)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if\ (Xik = 0 \;\&\&\; Yjk = 1) \\ Vijk = 1; Uijk = Wijk = 0; \end{matrix} \quad (8)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if\ (Xik = 1 \;\&\&\; Yjk = 1) \\ Wijk = 1; \end{matrix} \quad (9)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} if\ (Uijk = 1 \;\&\&\; (BMki = 1) \\ \text{DN}ijk = 1;\ \text{SC}ijk = 0; \end{matrix} \quad (10)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} \text{if } (\text{V}ijk = 0 \;\&\&\; (BPkj = 1) \\ \text{DN}ijk = 0;\ \text{SC}ijk = 1; \end{matrix} \quad (11)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} \text{if } (\text{DN}ijk = 1 \;\&\&\; (Ai < Dj * Sj) \\ \text{M}ijk = 1;\ \text{O}ijk = 0;\ \text{Z}ijk = 0; \end{matrix} \quad (12)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} \text{if } (\text{U}ijk = 0 \;||\; (\text{Ai} < Dj * Sj) \\ \text{M}ijk = 0;\ \text{O}ijk = 0;\ \text{Z}ijk = 0;; \end{matrix} \quad (13)$$

$$\sum_k^c \sum_i^M \sum_j^C \begin{matrix} \text{if } (\text{V}ijk = 0 \;||\; (\text{Ai} < Dj * Sj)) \\ \text{M}ijk = 0;\ \text{O}ijk = 0;\ \text{Z}ijk = 0; \end{matrix} \quad (14)$$

X_{ik}, Y_{jk}, U_{ijk}, V_{ijk}, BM_{ik}, BP_{jk}, DN_{ijk}, $SC_{ijk} = 0 / 1$ (15)

R_{ik}, Q_i = integer (16)

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. Equations 7 and 8 are stating conditions to assign values for U_{ijk} and V_{ijk} as 0 or 1as well as W_{ijk} as 0. Equation 9 is the condition to assign W_{ijk} as 1. Equations 10, 11, 12, 13 and 14 are the conditions to assign M_{ijk}, O_{ijk} and Z_{ijk} as 0 or 1with preconditions DNijk, SCijk as 0 or 1.

Input data

The incidence matrix of size M x N is the primary data input given as Inc [M][N] (Refer Table 1). Block diagonal form is considered for input as machine cell X [M][C] and part family Y [N][C] in terms of 0 and 1(Refer Table 2) 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[M], B[M], C[M]. 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[N], IA[N], S[N], D[N], D1[N] and V[N]. (Refer Table 1).

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 determined for those machines related to each bottleneck part.

Budgetary constraint

$$\sum_k^c \sum_{i\epsilon \mathbf{DM}}^M \sum_{j\epsilon \mathbf{SP}}^C \text{Mijk} \quad x \quad \text{Ai} \leq \text{Bik} \qquad (17)$$

In the analysis of exceptional elements, sometimes subcontracting the bottleneck parts will be dealt only because to check whether the bottleneck machines are to be considered for duplication or not.

The optimization model is used to solve all the Bench mark problems in Ilog Cplex 12.4.

An engine log for Bench mark problem 2 during execution is minimization Bench mark problem with 448 variables, 635 constraints.

Table: 4 Computational results: LPP OPL Cplex model solutions

Bench mark problem	**min Z** ₹	$\mathbf{Z_{ijk}}$	$\mathbf{M_{ijk}}$	$\mathbf{O_{ijk}}$	$\mathbf{W_{ijk}}$	**EE**
Bench mark problem1 7M X 8P	4,53,104	Z_{272}=15 Z_{772}=15	M_{121}=1	O_{272}=250 O_{772}=250	∑=242 (W_{471}= 15; W_{641}= 15; W_{262}=24; W_{783}=15)	3 (DM-1, SP-2)
Bench mark problem 2 10M X 8P	8,23,000	Z_{151}=10 Z_{951}=10	M_{732}=1 M_{681}=1	O_{151}=300 O_{951}=300	∑=224 (W_{361}= 12; W_{872}= 15, W_{543}=10)	4 (DM-2, SP-2)
Bench mark problem 3 9MX10P	18,30,205	Z_{411}=10, Z_{811}=10 Z_{811}=10, Z_{7103}=15	M_{821}=1 M_{242}, M_{262}=1 M_{773}=1	O_{411}=320 O_{811}=320 O_{7103}=280	∑=300 (W_{321}= 4; W_{542}=12, W_{673}=10)	7 (DM-4, SP-3)
Bench mark problem 4 10MX12P	5,66,841	Z_{851}=15 Z_{891}=12	M_{411}=1, M_{451}=1	O_{851}=300 O_{891}=300	∑=360 (W_{311}=10; W_{832}=14, W_{463}=12)	4 (DM-2, SP-2)
Bench mark problem 5 10MX20P	2,320	Z_{ijk}=0	M_{ijk}=0	O_{ijk}=0	∑=600 (W_{111}=15; W_{222}= 16; W_{5133}=15; W_{764}=12)	0
Bench mark problem 6 18MX24P	21,16,833	Z_{9241}=15, Z_{632}=14, Z_{1132}=15, Z_{1573}=14, Z_{8203}=10, Z_{15183}=14, Z_{13143}=20	M_{8241}, M_{8231}, M_{8101}=1; M_{15151}, M_{15171}=1; M_{1261}, M_{12221}=1; M_{542}, M_{5142}, M_{5112}, M_{5162}=1	O_{9241}=300 O_{632}=320 O_{1132}=330 O_{1573}=280 O_{8203}=250 O_{15183}=280 O_{13143}=300	∑=720 (W_{2231}=16; W_{932}=15; W_{14203}=16)	18 (DM-11, SP-7)

Discussion of results

In the solution of Bench mark problem1, out of 3 exceptional elements, bottleneck machine 1 is decided to be duplicated and estimated for intra movement costs with respect to their cell; component 7 is subcontracted for two operations. Sum of all intra movements are given and along with it, some movements are given one in each cell.

The duplication of machine 2 in Bench mark problem3 consecutively eliminates two exceptional elements. In Bench mark problem6, duplication of machine 8 consecutively eliminates three exceptional elements. Duplication of machine 15 eliminates two exceptional elements, duplication of machine 12 eliminates two exceptional elements and duplication of machine 5 eliminates four exceptional elements. The number of duplicating machines in the respective cells depends upon the total machining time the machine processing parts.

In this proposed model, once duplication of machines is done without subcontract of parts, hence there is no need to calculate the intercell movement's costs and subcontract costs. Significance will be given in case of finding both inter and the intra cell movement's costs if duplication as well as subcontract arises. Because of management investment policy, there will be restriction to increase in machine duplication from budgetary constraint and hence it tends to increase subcontract parts.

CELL LAYOUT DESIGN

Cell layout design is used in the physical configuration of cells, machine tools, and store room. The ultimate achievement of having a layout design is to facilitate a smooth flow of material, work, and information through the production system. The strategies followed in facility design, are flexible, optimum space utilization and minimum capital investment. Part volume to be processed takes vital role in locating the machinery within the cell and locating the cell within the shop floor as per determined preference order.

The input data are incidence matrix Inc[i][j], part demand D[j], machine length ML[i], machine cells X[k][i], part families Y[k][j], Bottleneck machines BM[k][i], Bottleneck parts BP[k][j], Duplicated machines DM[k][i] obtained from route sheets and block diagonal form. These input data are given to a C++ program to compute cumulative part volumes, finally to determine the cell's preference order and the machine's preference order.

Cell Supply

$$\sum_{k=1}^{Cells} CSk = \sum_{k=1}^{Cells}\sum_{i=1}^{M}\sum_{j=1}^{C} if\ (X[k][i]=1, Y[k][j]=1, Inc[i][j]=1)\ \ CSk \mathrel{+}= D[j]; + \sum_{k=1}^{Cells}\sum_{i=1}^{M}\sum_{j=1}^{C} if\ (BM[k][i]=1, BP[k][j]=1, DM[k][i]=1)\ \ CSk \mathrel{+}= D[j]; \quad (18)$$

Machine Supply

$$\sum_{k=1}^{Cells}\sum_{i=1}^{M} MSki = \sum_{k=1}^{Cells}\sum_{i=1}^{M}\sum_{j=1}^{C} if\ (X[k][i]=1, Y[k][j]=1, Inc[i][j]=1)\ \ MSki \mathrel{+}= D[j]; + \sum_{k=1}^{Cells}\sum_{i=1}^{M}\sum_{j=1}^{C} if\ (BM[k][i]=1, BP[k][j]=1, DM[k][i]=1)\ \ MSki \mathrel{+}= D[j]; \quad (19)$$

Dimensions of Cell

Length of a cell (L_k) = 2 A + 2 MW+ $\sum_{i=1}^{Ml}$ MLi (20)

Breadth of a cell (B_k) = 2 A + 1 MW + $\sum_{i=1}^{Mrs/Mls}$ MLi (21)

The aisle can be considered around 0.9m to 1.5m for small and medium size layouts and 1.5m to 1.8m for larger size layout according to the availability of floor area. But for effective material handling and supervision, the minimum lengths of the aisle 0.9m and 1.5m are preferred. In all these Bench mark problems, machine width is considered as 1.2m for all machines in smaller and medium size cellular layouts.

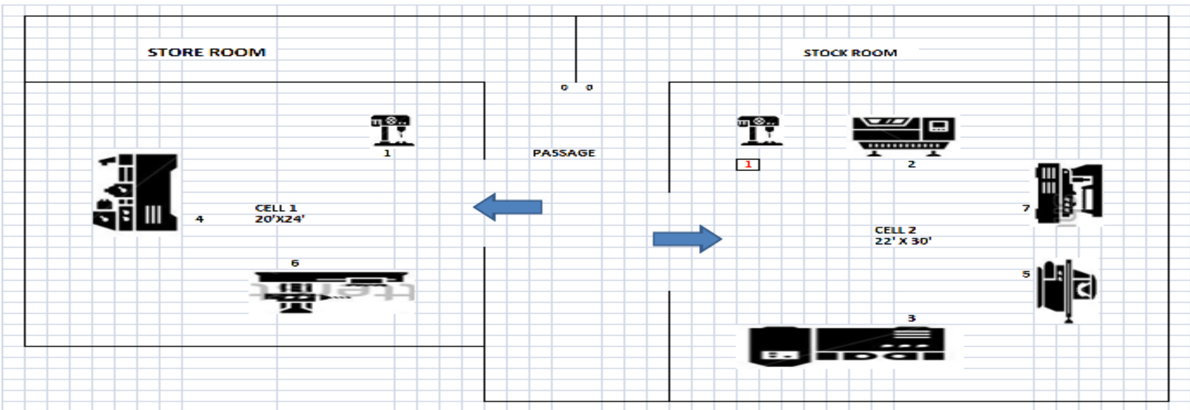

Fig.1 Cell layout design for Bench mark problem 1-7machines x 8 components Bench mark problem

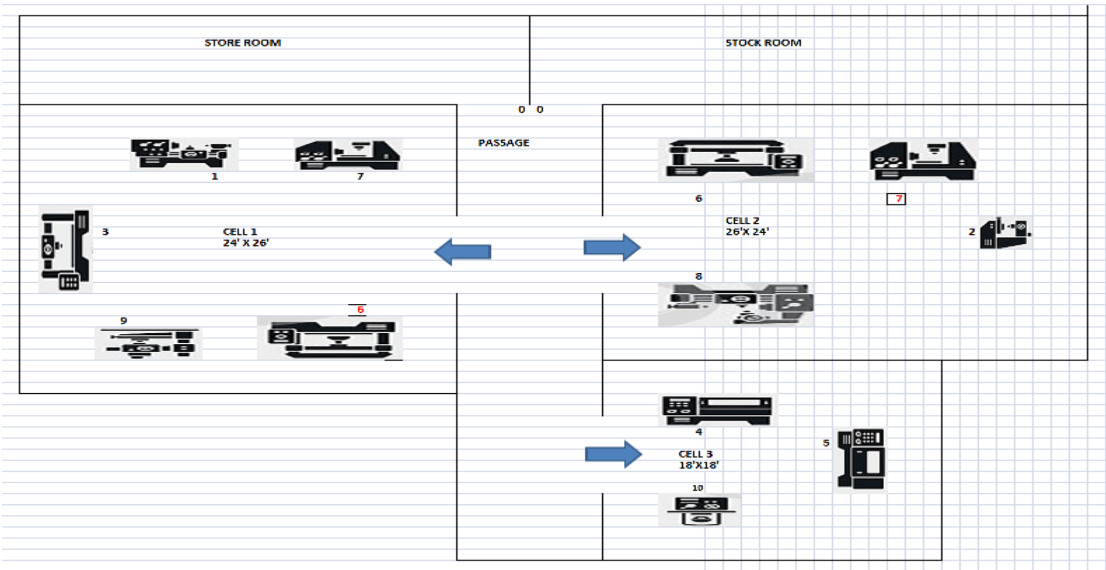

Fig.2 Cell layout design for Bench mark problem 2-10machines x 8 components Bench mark problem

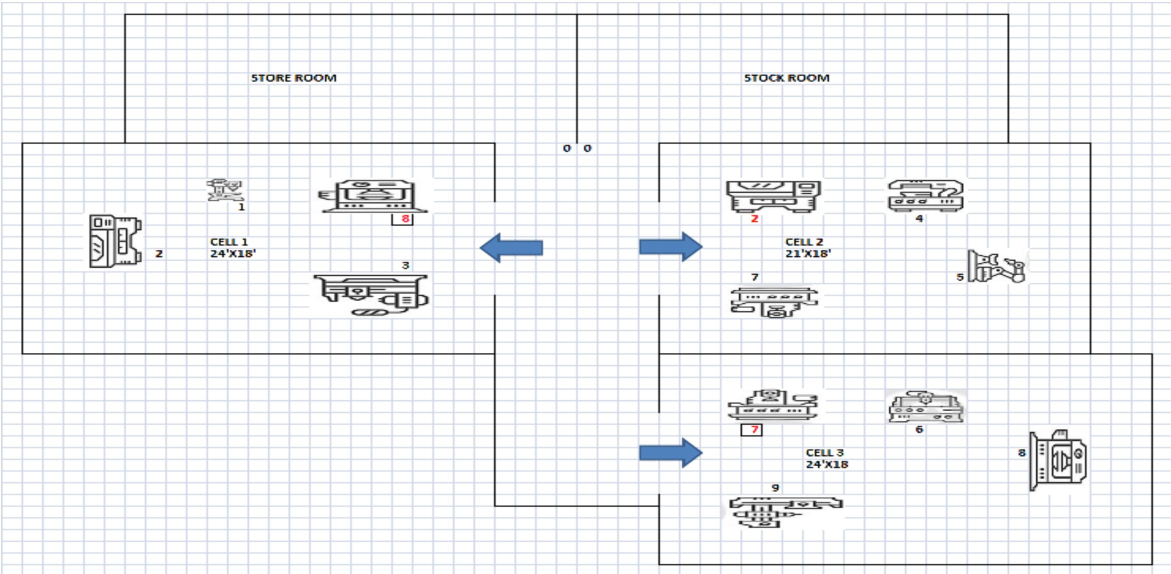

Fig.3 Cell layout design for Bench mark problem 3-9machines x 10 components Bench mark problem

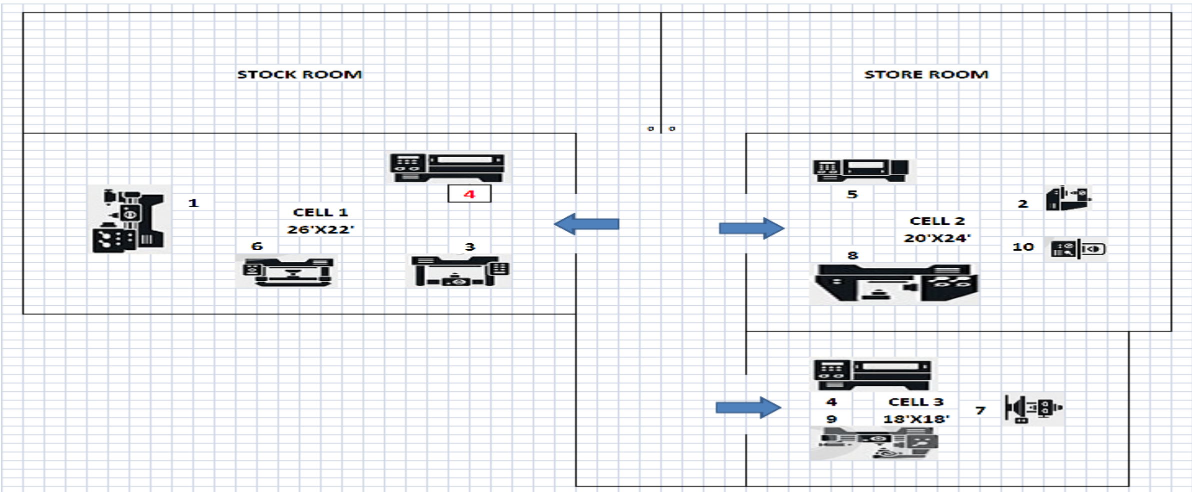

Fig.4 Cell layout design for Bench mark problem 4-10machines x 12 components Bench mark problem

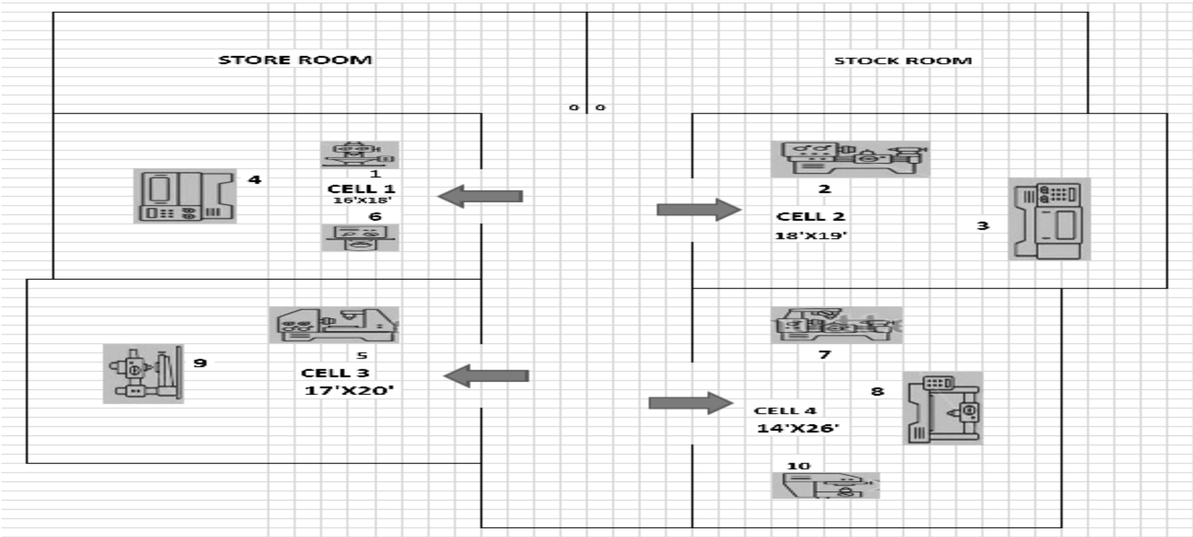

Fig.5 Cell layout design for Bench mark problem 5 -10machines x 20 components Bench mark problem

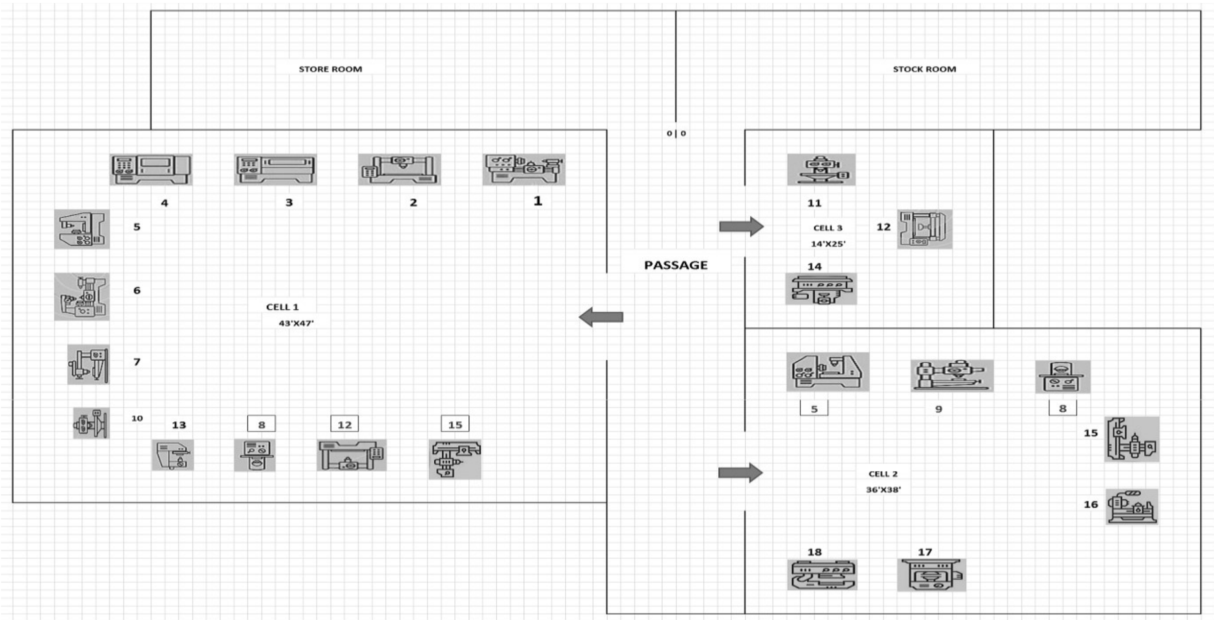

Fig.6 Cell layout design for Bench mark problem 6-18machines x 24 components Bench mark problem

Number of machines in the cell (M_k)

The machines are arranged in a U shaped layout to have effective intra movements of materials, tools, labor and supervision over the entire cell. The machines are divided into three sets equally and the first two full sets of machines are arranged along the right side, length wise and the remaining machines are arranged along the left side of the cell starting from the entry.

The shop floor layout is prepared to locate cells with respect to the storeroom and stock room. Raw materials are transferred from the storeroom to cells and finished parts are stocked in the stock room. The material handling systems are AGV, forklifts, trolleys, pallets and bins and most of the time by manual to and from the storeroom; the stock room and intra inter cells. Inter cell and intra cell movements are measured from the storeroom to the stock room through cells in machine clusters. The typical 2D shop floor layout plan is prepared with the apt scale to easily measure movement lengths and dimensions. Duplicated machines are also located within the respective cells given in the box. The material movement lengths are calculated with the help of distance matrix of machines as shown in Table 5.

Table 5 Distance matrix of machines (Bench mark problem 4, 10M X 12P)

M/M	1	2	3	4	5	6	7	8	9	10	Origin 0X0
1	0	36	15	14	32	10	55	35	52	32	30
2		0	30	32	8	36	22	12	26	6	25
3			0	8	24	8	35	20	40	28	24
4				0	26	40	6	15	6	24	36
5					0	32	26	6	24	14	16
6						0	30	28	44	30	30
7							0	20	8	18	38
8								0	20	8	20
9									0	20	38
10	Symmetric									0	28

Table 6 Cell layout design computed results compared to process layout

Bench mark problems	Cell location order	Machine location order	Floor area of Cell layout (m^2)	Floor area of Process layout (m^2)	Floor Area Saving in per- cent	Material movement length in Cell Layout (m)	Material movement length in Process lay out (m)	Movement Saving in percent
Bench mark problem1 7M X 8P	Cell 2	3, 1, 2, 5, 7	102.88	133.74	23%	223	396	44%
	Cell 1	1, 6, 4						
Bench mark problem 2 10M X 8P	Cell 2	6, 8, 7, 2	141.88	175.93	19%	348	548	36%
	Cell 1	7, 6, 1, 9, 3						
	Cell 3	4, 10, 5						
Bench mark problem 3 9MX10P	Cell 1	2, 7, 4, 5	112.07	132.24	15%	257	420	39%
	Cell 2	8, 3, 1, 2						
	Cell 3	7, 9, 6, 8						
Bench mark problem 4 10MX12P	Cell2	5, 8, 2, 10	124.18	167.64	26%	341	486	30%
	Cell 1	4, 3, 6, 1						
	Cell 3	4, 9, 7						
Bench mark problem 5 10MX20P	Cell 2	2, 3	118.61	151.81	22%	487	690	29%
	Cell 1	1, 6, 4						
	Cell 4	7, 10, 8						
	Cell 3	5, 9						
Bench mark problem 6 18MX24P	Cell 3	11, 14, 12	332.53	458.89	28%	1292	1680	23%
	Cell 1	1, 2, 15, 12, 3, 4, 8, 13, 5, 6, 7, 10						
	Cell 2	5, 18, 9, 17, 8, 15, 16						

Discussion of results

Cell layout design is prepared as 2D shop floor plan as per suitable scale to have easy measuring lengths. All these cells and machines are located with respect to the storeroom and stock room with an adjacent entry as origin. The cell and machine locations can be measured as rectilinear from the origin for an easy plotting of the shop floor. The aisle of cells, machines, and the partitions are considered as per problem size. The central passage aisle is allowed suitably related to the size of the part volume to be handled. Cell order and machine order are helpful in locating the cells and machines in shop floor and respective cells. A process layout is considered as separate layouts for similar machines to process the bunch of part volumes. 2D shop floor plans are prepared with the input of cell order, machine order and machine dimensions. The outcomes obtained from this layout design are the floor area required by each cell and savings in the floor area compared to the traditional process layout and distances travelled by each job in and between cells are also calculated using C++ program and saved in distances travelled compared to process layout are given in Table 5. The saving of the floor area and movement length is irrespective of Bench mark problem size, but solely depends on types of machinery provided and part volumes handled.

CONCLUSIONS

Good clusters of machine cells are achieved to make use of floor area saving which is finally reducing human movements. The results of the optimization model are the costs of EE, while the estimation of the costs of duplication, subcontract and inter intra movements considered significantly the budgetary constraint of duplication and economic tradeoff of parts subcontract. This approach proved that this could be fitted to any size of the part volume with less floor area. Floor area saving leads to effective overall control of operations in every cell and distance travelled saving leads to easier operations and time saving.

This approach proved through cell layout design as well as a linear programming model that this could be fitted to any size of the part volume with less floor area. In the future, the proposed mathematical approach can be extended for scheduling as well as a line balancing through heuristic clustering by doing simulation considering within the shop floor with respect to the warehouse and storeroom as well as inventory for raw materials, the work-in process.

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APPENDIX

Notations:

A	Aisle between machines or machine to side walls,
A_i	Cost of machine type i,
a_{ij}	1 if part j assigned to machine i, 0 otherwise,
a_{xi}	1, if part type x visits machine i; 0 otherwise
a_{xjr}	1 if part type j assigned to machine x with process plan r; 0 otherwise
a_{yi}	1, if part type y assigned to machine j; 0 otherwise
a_{yjr}	1, if part type j assigned to machine y with process plan r; 0 otherwise;
B_{ik}	Budget allowed duplicating the bottleneck machine i,
BM, BP	Set of pairs of bottleneck machines, bottleneck parts (i, j)
BS_{1x} and BS_{1y}	No. of future batches of part x and y rounded to the whole, D_{1x}/V_x, D_{1y}/V_y
BS_x and BS_y	No. of batches of part x and y rounded to the whole, D_x/V_x, D_y/V_y
C	Number of components,
C_i	Periodic capacity of machine type i,
C_k	Number of jobs in the k_{th} cell,
D_j	Periodic demand for part j,
DM	Duplicated machines set connected to exceptional component j,
DN, SC	Set of pairs of duplicated machines, subcontract parts (i, j)
D_x and D_y	demand of part type x and y per period
EE	No. of exceptional elements;
I	= 1..., M (machines index),
IAj	Handling cost for a unit of part j within one cell,
I_j	Handling cost for a unit of part j between two cells,
j	=1…, N (parts index),
K	=1…, N_c (cells index)
M_l	Number of machines along lengthwise of the cell,
M	Number of machines,
M_k	Number of machines in the k_{th} cell,
ML_i	Machine length considered from the dimensions of machine i,
M_{rs}/M_{ls}	Number of machines along the right side and left side of the cell.
MT_{ij}	Machining time of machine i required for part j,
MU	Machine utilization,
MW	Machine width considered as constant for all machines,
N	Total number of operations
N_{01}	Total number of operations within the block diagonals,
N_c	Number of cells formed,
n_j	Number of operations a part j undergoes
n_k	Number of operations in the k^{th} cell;
PBs_j	Ratio of no. of batches of part j, BS_j / BS_{1j}
p_j (x_k)	Probability of operations in the j^{th} job
q	Weighing factor $0 \leq q \leq 1$=0.5;
Q_i	Number of machine type i required to process parts in machine cells (integer),
p	= 1.., P (process plans)
R_{ik}	Number of machine type i to be purchased for cell k (integer),
S_j	Subcontracting cost of a part j for a process,
UC_{ij}	Usage capacity of machine i for part j (MT_{ij} D_j / C_i),
V_x and V_y	Batch size of part type x and y per period
w_k	Frequency of operations in the k^{th} part family / cell;
X_{ik}, Y_{jk}	1 if machine i and part j occurs in cell k respectively, 0 otherwise