

Complete Similarity Measure Mathematical Model For Cell Layout Design

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Abstract

The presented mathematical model is used to form machine cells, optimize costs of exceptional elements and design the shop floor layout for various demands of components. The complete similarity measure algorithm forms machine cells and part families in a refined form. Later, exceptional elements are eliminated in linear programming optimization model by using machine duplication and part subcontract. Then the shop floor layout is designed to have optimized material movements between cells and within a cell. The performance evaluation of cell formation algorithm is done on case studies of various batch sizes to give the process capability compared with other similar methods. The result from a linear programming optimization model is cost savings, machines duplicated, parts subcontracted, inter intra cellular movements. Finally, the output of inbound facility design is the floor layout which has machine cell clusters with optimized floor area.

Keywords Complete similarity measure, PARI model, Exceptional elements, Grouping efficiency, Machine Utilization, Machine duplication, Parts subcontract, Cell layout design.

1. Introduction

The Cellular Manufacturing (CM) works to increase productivity and production efficiency by reducing processing time, work-in progress and material movement time and the end use is reduced human effort. In a CM system, identical 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. Among various matrix formulation similarity coefficient methods such as direct clustering, bond energy algorithm, rank order clustering approaches, here a complete Similarity Coefficient Method (SCM) is used because of its easy clustering capability and more flexible in having production data, for example, process plan, part demand and processing time.

The cell formation will have Exceptional Elements (EE), i.e. exceptional machines and parts. EE creates interactions between two manufacturing cells and Void Elements (VE) i.e. inside block diagonals which affect machine utilization and grouping efficiency. An exceptional component requires manufacturing on machines in two or more cells and an exceptional machine manufactures parts from two or more part families. The cell layout will have work cells inside 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.

In this proposed work, in the section 3, machine cells are formed, by using the proposed similarity coefficient between machines and components as well as refining clusters by using weight based approach in-line, over the similarity measure proposed lastly by Garbie et al. [1]. At last, performance evaluation is carried out through Machine Utilization MU, the Grouping Efficiency GE and percentage of Exceptional Elements EE. In the section 4, a linear programming model is developed to reduce the cost of exceptional elements over costs reduction given by Arikan and Gungor [2]. In section 5, the sizes of cells, positioning cells as well as machines are determined with the help of the sort of cells and sort of machines with respect to origin and finally a 2D shop floor layout is designed.

2. Literature review

2.1 Review on similarity coefficient mathematical approaches

In this section, the review is conducted over recent literature of mathematical approaches using various similarity coefficients. The work by Adinarayanan et al. [3] discussed the cell formation problem, with the objective of minimizing the cumulative cell load variation and cumulative intercellular moves. The quantity of parts, operation sequences, processing time, capacity of machines, and workload of machineries were considered as parameters. For the grouping of equipment, the modified artificial bee colony (MABC) algorithm is considered. In the article by Nair, Narendran [4], a new similarity coefficient is incorporated with the job sequence and part volume to form cells alone. The approach given by Albadawi et al. [5] preferred to apply Jaccard's similarity coefficient for forming cells alone using the principal component analysis. Garbie et al. [1] proposed a new similarity coefficient contains process plans, operation time, demand, production volume which able to form machine cells alone. Kumar, Sharma [6] used job sequence, part volume, inter-cell movement cost, job production cost, the alternate process plans in the proposed

similarity coefficient-based heuristic method for CM. The review revealed that similarity coefficient can possess parameters such as job sequence, setup and handling time, changes in demand and volume in addition to machining time, machine capacity, and a number of operations to have capability to form the perfect machine and part clusters simultaneously without or few exceptional elements which can overcome the difficulties faced by other methods. A new similarity coefficient algorithm is proposed by Shanmugasundaram and Anbumalar [7] to form the machine cell and part families' identification. This proposed algorithm is tested by using standard problems and compared with other CF method results. The quality of the algorithm is measured by using Grouping efficiency and grouping efficacies which are most widely used measures the superiority of cellular manufacturing systems. The proposal in the literature of Yingyu Zhu and Simon [8] used to advance the similarity coefficient method to solve cell formation (CF) problems in two aspects. Firstly, a weighted sum formulation is applied to aggregate them into a non binary matrix to indicate the dependency strength among machines and parts and secondly, a two mode similarity coefficient is applied to simultaneously form machine groups and part families based on the classical framework of hierarchical clustering. Shilpa, Neela [9] has proposed a very simple yet effective method for clustering which tried to minimize the intracellular movement with maximum grouping efficiency and maximum machine utilization. The paper have provided a new model by considering dynamic production times and uncertainty demands in designing cells for test problem with real-world dimensions has been solved using simulated annealing and particle swarm algorithms given by Ayough, Khorshidvand [10]. A new multi-objective mathematical model is provided for cell formation with consideration of machine reliability and alternative process plans in the article of Masoud et al. [11].

Zlatan, Tonci [12] proposed the model was incorporated into dynamic cell formation, worker and machine assignments, machine hardness level, route and workerexibility, operation sequence, product quality level, worker and machine capacity, and worker's skill level under uncertainty. The proposed algorithm takes into account the similarity of manufacturing sequence and by simple one to one comparison; it clubs together the components. The similarity coefficient clustering mathematical method is flexible in having production parameters in dynamic conditions over different time intervals to get possible closer values for cell formation and part grouping.

2.2 Review on cell formation costs optimization models

This section of review is aimed to evaluate elimination of costs directly related to the exceptional elements. The modified genetic algorithm given by Iraj et al. [13] for interchanging block diagonal form is for reducing voids inside cells and exceptional elements outside cells. Two alternative actions are evaluated by Chalapathi [14] a bottleneck machine can be duplicated, or it may be allowed and manufacturing parameters are incorporated into the proposed simulation study such as job sequence; batch size and setup time in comparing the cost of alternatives. Parametric programming proposed by Arikan and Gungor [2] is used to reduce the cost of an exceptional element, to decrease a number of outer cell operations and to increase utilized machine capacity. Chang-Chun, Chung-ying [15] proposed the model to reduce the number of movements between cells, voids and EEs, minimizes the total cost of duplicated machines without considering processing time of operations. Mahdavi et al. [16] proposed a model which considered reducing the cost of to and fro movements between cells and within the cells and the investment cost of machines. The literature given by Hashemoghli et al. [17] is proposed a bi-objective possibilistic nonlinear mixed-integer programming model 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.

The literature of Amir et al. [18] proposed a nonlinear programming model under potentially dynamic conditions which minimizes the cost associated for the estimated demands for inter/intra cellular movements of elements (forward and backward movements), the existence of exceptional elements, intercellular displacement of machines and cellular reconfiguration and operational costs and constant cost of machineries. The above reviews yielded that cost elimination of EE must look into intra cell movements and intercellular movements significantly by correlating machine duplication and part subcontract respectively.

2.3 Review on facility cell layout

A systematic methodology by Wai-Tien et al. [19] was developed to combine the same machines into the cell which is simulated and the outcome of the cell design is evaluated by analysis of variance. A split departmental plant layout generation system given by Gopalakrishnan et al. [20] is described to develop facilities layouts design that will minimize the material handling costs. Sui Pheng Low et al. [21] have examined that how lean production principles have significant impact on the dimensions of ramp-up factories, include length, clear inside height. Both the mapping of materials flows, the optimisation of lay-out given by Petrillo et al. [22] were considered through the integration of different operative techniques and commercial software. Xiaodong et al. [24] given a layout optimization model is formulated based on fuzzy demand and machine flexibility and then developed a genetic algorithm. Behrad et al. [28] proposed a multi- objective mixed integer nonlinear programming model has been proposed where areas of departments are unequal. Another feature of this paper is the consideration of input and output points for each department, which is crucial for the establishment of practical facility layouts in the real world. It is commonly known that facility layout design determines arrangement, location and distribution of machines in a manufacturing facility to achieve minimization of make-span time, maximization of productivity given in the literature of Tsehaye et al. [29]. The paper

presented four different MIP models for the single row facility layout problem with simultaneous asymmetric material flow and corridor width are developed based on the decision variable paradigm given by Xuhong et al. [30]. The outcome from the review showed that the facility cell layout must be an effective space saver and in reducing the material movement lengths.

3. Pragmatic Algorithm of a Resumptive Inline (PARI) model

Proposed PARI model is forming machine cell and part family clusters in two stages. In the first stage, similarity coefficient algorithm is forming machine cells, part families. In the second stage, as resumption, the same clusters are iterated by weighting based method to get proper partitioning. The modus operandi of generating high similarity matrices is incorporating a job sequence weight ratio, setup and handling time in processing time ratio, the ratio of present and new batch sizes which are having significant impact on finding complete similarity for machines as well as components. The authors incorporate necessary manufacturing data such as alternative process plans and job sequences to improve similarity coefficient to process the input data over the other similarity coefficients. The data of manufacturing times are acquired and tabulated in part incidence matrix which are used as input for algorithm.

3.1. Complete similarity measure weight based algorithm

The process plan-weight ratio is calculated between the sequence weight and number of operations to be done on the part. Ratio of batch size is calculated between new batch size and the present batch size of parts. Batch size is the ratio between demand and production volume. The use of the time ratio, the sequence weight ratio and the batch size ratio will help in boosting the similarity between machines as well as parts.

3.2. Notations:

3.2.1. Parameters

BS_{1x} and BS_{1y}	No. of future batches of part x and y rounded to whole, $D_{1x}/V_x, D_{1y}/V_y$
BS_x and BS_y	No. of batches of part x and y rounded to whole, $D_x/V_x, D_y/V_y$
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,
D_x and D_y	demand of part type x and y per period
MT_{ij}	Machining time of machine i required for part j,
n_j	Number of operations a part j undergoes
n_k	Number of operations in 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
ST_{ij}	Setup Time for processing part j in machine i.
SC_{xy}^M	Similarity Coefficient for machines x and y
SC_{xy}^C	Similarity Coefficient for parts x and y
sp_{xj}, sp_{yj}	Process sequences of part j in machines x and y respectively;
t_{ix} / C_{ix}	Ratio of processing time which part x in machine i with cycle time of part x.
t_{iy} / C_{iy}	Ratio of processing time which part y in machine i with cycle time of part y.
t_{jxr} / C_{tx}	Ratio of machining time which part j in machine x with cycle time of part j;
t_{jyr} / C_{ty}	Ratio of machining time which part j in machine y with cycle time of part j;
V_x and V_y	Batch size of part type x and y per period
W_{ij}	Waiting time of part j in machine i.
w_k	Frequency of operations in the k^{th} part family / cell;
$(n_{oj}-sp_{xj}+1)/n_{oj}$	Proportion of job sequence weight and no. of operations to be done on part j; this term represents the ratio of process sequence weight of machine x, p_{swxj} ;
$(n_{oj}-sp_{yj}+1)/n_{oj}$	Proportion of job sequence weight and no. of operations available on machine y; this term represents the ratio of process sequence weight of machine y, p_{swyi} ;

3.2.2. Indices

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;
i	= 1..., M (machines index),
j	=1..., N (parts index),
k	=1..., N_c (cells index)
p	= 1..., P (process plans)

The cycle time of each part is calculated by considering sum of waiting time, setup time and handling time which are assumed just equal to machining time for each operation to be performed in the machine.

$$C_{ij} = \sum_i^M (MT_{ij} + W_{ij} + ST_{ij} + H_{ij}) \quad \forall j \quad (1)$$

From the assumptions of the model, cycle time is just double the value of machining time of each operation of part.

$$\sum_j^C MT_{ij} \approx W_{ij} + ST_{ij} + H_{ij} \quad \forall i \quad (2)$$

The process sequence weight ratio is calculated between weight of sequence of the particular operation and total number of operations to be performed in the part.

$$Psw_{xi} = (noj - spxj + 1)/noj \quad (3)$$

For machines, compute similarity coefficient between machines x, y (for forming machine cells) using the equation (4), $SC_{xy}^M = 1$ if $x = y$;

$$SCM_{xy} = \frac{\sum_{j=1}^C \sum_{p \in nx \& ny}^P [\max(\frac{Mtjxp}{Ctj} X \frac{noj-spxj+1}{noj}) : (\frac{Mtjyp}{Ctj} X \frac{noj-spyj+1}{noj})] \text{ axjp. ayjp} X Pbsj}{\sum_{j=1}^C \sum_{p \in nx \& ny}^P \max[(\frac{Mtjxp}{Ctj} X \frac{noj-spxj+1}{noj}) \text{ axjp} : (\frac{Mtjyp}{Ctj} X \frac{noj-spyj+1}{noj}) \text{ ayjp}] X Pbsj} \quad \forall x, y \quad (4)$$

The Similarity Coefficient SC_{xy}^M is calculated between machines and similarity coefficient matrix will be formulated from the input part incidence matrix along with production data considering all alternative process plans.

For parts, compute similarity coefficient between parts x, y (for forming part family) using the equation (5).

$$SC_{xy}^C = 1 \quad \text{if } x = y;$$

$$SCC_{xy} = \frac{\sum_{i=1}^M [\max(\frac{Mtix}{Ctx} X \frac{Bsx}{Bs1x} X pswxi : \frac{Mtiy}{Cty} X \frac{Bsy}{Bs1y} X pswyi). \text{ axi. ayi}]}{\sum_{i=1}^M \max[\frac{Mtix}{Ctx} X \frac{Bsx}{Bs1x} . \text{ axi. pswxi} : \frac{Mtiy}{Cty} X \frac{Bsy}{Bs1y} . \text{ ayi. pswyi}]} \quad \forall x, y \quad (5)$$

The similarity coefficient of parts SC_{xy}^C is calculated and matrix is formulated for each of process plans. Number of parts similarity coefficient matrices will be equal to number of process plans. Good cluster is chosen among various process plans parts matrices.

Please insert **Fig.1** Flow chart for phases of work.

The quintessential proposal in similarity measure is inclusion of manufacturing data proportions having significant impact on similarity which end use is to generate simultaneously perfect clusters of machine cells and part families. The pragmatic algorithm is coded and executed for generation of similarity matrices using C++ programming language (using 2.13 GHz Core 5 Pentium processor), production data are given as input and the output is obtained as similarity coefficient matrices and block diagonal form is obtained through iterations using spreadsheet simulation.

The weights for rows and columns of similarity coefficient matrix (machine-machine matrix) are calculated using the equation (6), equation (7),

$$\sum_{y=1}^M SC_{xy} \times X (M - y) \text{ for rows} \quad (6)$$

$$\sum_{x=1}^M SC_{xy} \times X (M - x) \text{ for columns} \quad (7)$$

Select $X > 1$, Replace M by C for part - part similarity matrix. Arrange the rows and columns in the descending order of magnitude of the weights obtained.

After initial clustering, assign weights to each part /a machine to cell / part family using equation (8), equation (9).

$$w_k = x_k \times p_j (x_k) \quad (8)$$

$$\text{where } p_j (x_k) = 1 / n_j \quad (9)$$

Component / machine are assigned to the machine cell / part family where it has scored the highest weight and then the other.

3.3 Algorithm for PARI model

Step1 Let input is the MP Incidence matrix with production data, calculate cycle time for each operation with manufacturing time using eqns. 1 and 2 and then calculate process sequence weight ratio using eqn.3,

Step2 Compute SC_{xy} for machines using eqn.4 and formulate a machine similarity matrix and compute SC_{xy} for parts using eqn.5 and formulate parts similarity matrix.

Step3 Compute weights for rows and columns of similarity matrices using eqns 6 and 7.

Step4 Sort in descending order of weights in rows and then columns.

Step5 Iterate step2 and step3 using spreadsheet simulation until there is no change in the order of rows and columns in matrices.

Step6 Identify machine cells and part families from corresponding matrices and formulate block diagonal form by correlating with the incidence matrix.

Step7 Use rule of thumb, i.e., if no. of parts are more than machines, first refine part families otherwise refine machine cells.

Step8 Compute weights of parts/machines w.r.t. machine cells/part families using eqns 8 and 9.

Step9 Finally assign the parts/machines to cells/families where they have scored more weights.

Step10 Then refine parts families/machine cells to get final block diagonal form. Stop

3.4 Assumptions for the PARI algorithm and optimization model

1. The manufacturing time of operations for alternative process plans are acquired as input data.
2. One or more job sequences of all operations for all part types over machines are known.
3. The current, future demands and batch sizes of parts are known for fixed periodic intervals and no of batches are also calculated.
4. The purchase price and the duplication budget are known for all machine types.
5. Subcontract price; inter cell and intra cell movement costs are known for all parts.
6. The entire demand of each part has to be completed in the manufacturing within the time period.
7. The machines to be duplicated, parts to be subcontracted, inter and intra movements are taken as decision variables.
8. All machines can process one or more operations (i.e., machine flexibility).

3.5. Numerical illustration

The selected bench mark problems (literature references of five mathematical and one metaheuristic approaches of different sizes are mentioned in each input Bench mark problem) of small, moderate and large in size, in machine component incidence matrices are solved. The data of part incidence, machining time, job sequence, demand and production volume, machine capacity are acquired and tabulated which are given as input for generating similarity matrices.

Bench mark problem 1: 7machinesX 8 Components. (Input Data from Murugan & Selladurai [23] Cells are grouped after 4 iterations, part families are formed after 10 iterations. After weighting based approach used in a series, block diagonal form is obtained.

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 are refined and then part families to have perfect clusters because parts are less than the machines. In this solution, VE is only one and EEs are 4 as in the Table 2.

Please insert **Table1: Incidence matrix with production data.** (Input Data from Hachicha et al. [25])

Bench mark problem 3: 9Machines X 10 Components (Input data from Albadawi et al. [5]) The machine and part similarity matrices are transformed into block diagonal form after 3 iterations and 5 iterations respectively and cells, part families are formed.

Bench mark problem 4:10Machines X 12Components (Input Data from Arikan and Gungor [2]) The machine and part similarity matrices are transformed into block diagonal form in the spreadsheet simulation after 3 iterations and 7 iterations respectively.

Bench mark problem 5:10Machines X 20Components (Input data from Dixit and Mishra [26]) The incidence matrix is transformed using similarity coefficient heuristic algorithm, cells are formed after 3 iterations, part families are also formed after 2 iterations. After weighting based approach used in a series, relocations of clusters have taken place in horizontal and vertical directions; finally block diagonal form is obtained.

Bench mark problem 6:18Machines X 24Components (Input data from Faouzi et al. [27]) Block diagonal form is now formed through iterations in similarity and weight based methods over machine and part matrices after 7 iterations and 10 iterations respectively.

Please insert **Table2: Block diagonal form**

3.6 Evaluation through performance criteria for 10 x 8 machines – components Bench mark problem:

Machine Utilization:

Machine Utilization is a parameter for measuring the goodness of a solution. It denotes the proportion of time the machines with in cells are used in production.

$$MU = N01 / \sum_{k=1}^{Nc} Mk \times Ck \quad (10)$$

$$N_{01} = 26; \quad M_{k1} = 4 \quad C_{k1} = 3; \quad M_{k2} = 3; \quad C_{k2} = 2;$$

$$M_{k3} = 3, \quad C_{k3} = 3;$$

MU is 96%.

Grouping efficiency:

$$GrE = (1-q) \times 1 - \left\{ \frac{EE}{(M \times C) \sum_{k=1}^{Nc} (MK \times CK)} \right\} + q \times MU \quad (11)$$

GrE is 98%.

Percentage of exceptional elements:

A number of elements that occur out of the diagonal blocks are called as exceptional elements which denote the impact of cell formation. The best cell formation approach ends in a less percentage of exceptional elements.

$$PE = \frac{EE}{N} \quad (12)$$

Where, C Number of components,
 EE No. of exceptional elements;,
 GE Grouping Efficiency,
 MU Machine utilization,
 M Number of machines,

N	Total number of operations,
M_k	Number of machines in the k_{th} cell,
N_{01}	Total number of operations within the block diagonals,
N_c	Number of cells formed,
q	Weighing factor $0 \leq q \leq 1=0.5$;

For EE = 4, out of 30 (N), PE is 13%; criteria for other problems are shown in the Table 3.

Please insert **Table 3: Comparison of results – P.A.R.I. algorithm and other best-known approaches**

3.7 Discussion of results

This proposed P.A.R.I algorithm giving good solution with minimal or no number of exceptional elements as one of the objectives. The solution of small and medium size bench mark problems (1, 2, 3, 4 and 5) has few EE as well as VE. The machine grouping is effective in large size bench mark problems, and it has less EE and VE.

The small and moderate part machine-component bench mark problems (bench mark problems 1, 2, 3 and 4) are solved effectively in less iteration time to get goodness of solution. The large size machine component bench mark problems (bench mark problems 5 and 6) are solved with more than the average performance with respect to typical methodologies. EEs are equal in Bench mark problem 4 with a Bench mark problem, but inter cell movements are less, voids are more compared to Bench mark problem solution. The block diagonal form is given as input for an optimization model and facility layout design and transformed into a shop floor layout design for all the Case Studies in section 4.

4. Optimization model

The aim of the proposed linear programming model is 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 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 [2]. The other proposal in this model is the inclusion of the budget constraint to set the limit for the machine duplication.

4.1. Notations: Parameters:

A_i	Cost of machine type i,
B_{ik}	Budget allowed to duplicate the bottleneck machine i,
BM, BP	Set of pairs of bottleneck machines, bottleneck parts (i, j)
DM	Duplicated machines set connected to exceptional component j,
DN, SC	Set of pairs of duplicated machines, subcontract parts (i, j)
IA_j	Handling cost for a unit of part j within one cell,
I_j	Handling cost for a unit of part j between two cells,
Q_i	Number of machine type i required to process parts in machine cells (integer),
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,
X_{ik}, Y_{jk}	1 if machine i and part j occurs in cell k respectively, 0 otherwise
UC_{ij}	Usage capacity of machine i for part j ($MT_{ij} D_j / C_i$),

4.2. Decision variables

Z_{ijk}	- Number of intercell movements required by part j when 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 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.

Objective function is to maximize the savings by,

Minimizing

$$\sum_k^c \sum_i^M \sum_j^C (A_i \cdot M_{ijk}) + \sum_k^c \sum_i^M \sum_j^C (I_j \cdot Z_{ijk} \cdot B_{sj}) + \sum_k^c \sum_i^M \sum_j^C (S_j \cdot O_{ijk} \cdot D_j) + \sum_k^c \sum_i^M \sum_j^C (IA_i \cdot W_{ijk} \cdot B_{sj}) \quad (13)$$

Eq. (13) is an objective function which is to minimize machine duplication cost, intercellular movement cost, parts subcontracting cost and intracellular movement cost.

Step2: 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,

$$X_{ik} - Y_{jk} + U_{ijk} - V_{ijk} = 0 \quad (14)$$

$$\sum_k^c \sum_i^M \sum_j^c MT_{ij} \times D_j \leq C_i \quad (15)$$

$$\sum_i^M \sum_j^c M_{ijk} \leq R_{ik} \quad (16)$$

$$C_i / (MT_{ij} \times D_j) \geq Q_i \quad (17)$$

$$\sum_k^c \sum_i^M \sum_j^c M_{ijk} \times MT_{ij} \times D_j \leq C_i \quad (18)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (X_{ik} = 1 \ \&\& \ Y_{jk} = 0) \\ U_{ijk} = 1; V_{ijk} = W_{ijk} = 0; \end{matrix} \quad (19)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (X_{ik} = 0 \ \&\& \ Y_{jk} = 1) \\ V_{ijk} = 1; U_{ijk} = W_{ijk} = 0; \end{matrix} \quad (20)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (X_{ik} = 1 \ \&\& \ Y_{jk} = 1) \\ W_{ijk} = 1; \end{matrix} \quad (21)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (U_{ijk} = 1 \ \&\& \ (BM_{ki} = 1)) \\ DN_{ijk} = 1; SC_{ijk} = 0; \end{matrix} \quad (22)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (V_{ijk} = 0 \ \&\& \ (BP_{kj} = 1)) \\ DN_{ijk} = 0; SC_{ijk} = 1; \end{matrix} \quad (23)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (DN_{ijk} = 1 \ \&\& \ (A_i < D_j * S_j)) \\ M_{ijk} = 1; O_{ijk} = 0; Z_{ijk} = 0; \end{matrix} \quad (24)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (U_{ijk} = 0 \ || \ (A_i < D_j * S_j)) \\ M_{ijk} = 0; O_{ijk} = 0; Z_{ijk} = 0; \end{matrix} \quad (25)$$

$$\sum_k^c \sum_i^M \sum_j^c \begin{matrix} \text{if } (V_{ijk} = 0 \ || \ (A_i < D_j * S_j)) \\ M_{ijk} = 0; O_{ijk} = 0; Z_{ijk} = 0; \end{matrix} \quad (26)$$

$$X_{ik}, Y_{jk}, U_{ijk}, V_{ijk}, BM_{ik}, BP_{jk}, DN_{ijk}, SC_{ijk} = 0 \text{ or } 1 \quad (27)$$

$$R_{ik}, Q_i = \text{integer} \quad (28)$$

Eq. (14) is ensuring each machine and component is assigned in one cell only. Eq. (15) ensures that the sum of machining times of operations in each machine is within the capacity. Eq. (16) 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. Eq. (17) is to ensure a number of each machine type is within its utilization capacity otherwise its number will increase. Eq. (18) 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. Eq. (19) and Eq. (20) are stating conditions to assign values for U_{ijk} and V_{ijk} as 0 or 1 as well as W_{ijk} as 0. Eq. (21) is the condition to assign W_{ijk} as 1. Equations 22, 23, 24 25 and 26 are the conditions to assign M_{ijk} , O_{ijk} and Z_{ijk} as 0 or 1 with preconditions DN_{ijk} , SC_{ijk} as 0 or 1.

4.3. Input data

The incidence matrix of size $M \times N$ 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.

Step4: The constraint for duplication budget is formulated using procure cost determined for those machines related to each bottleneck part.

4.4. Budgetary constraint

$$\sum_k^c \sum_{i \in DM}^M \sum_{j \in SP}^c M_{ijk} \times A_i \leq B_{ik} \quad (29)$$

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 12.2.

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

Please insert **Table: 4 Computational results: LPP OPL Cplex model solutions**

4.5. 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.

5. Cell layout design

The location of cells in a manufacturing industry considers the parts volume supplied to each cell and parts volume allotted to each machine in the respective cell. The strategies followed in facility design are flexibility, 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.

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.

Please insert **Fig.2** *Cell layout design for Bench mark problem 1-7machines x 8 components Bench mark problem*

Please insert **Fig.3** *Cell layout design for Bench mark problem 2-10machines x 8 components Bench mark problem:*

Please insert **Fig.4** *Cell layout design for Bench mark problem 3-9machines x 10 components Bench mark problem:*

Please insert **Fig.5** *Cell layout design for Bench mark problem 4-10machines x 12 components Bench mark problem*

Please insert **Fig. 6** *Cell layout design for Bench mark problem 5 -10machines x 20 components Bench mark problem:*

Please insert **Fig.7** *Cell layout design for Bench mark problem 6-18machines x 24 components Bench mark problem:*

5.1. Number of machines in the cell (M_k)

The machines are arranged in U shaped layout to have effective intra movements of materials, tools, labour 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 storeroom and stock room. Raw materials are transferred from the storeroom to cells and finished parts are stocked in stock room. The material handling systems used nowadays in cell layout 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. 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.

5.2. Discussion or results

The cell and machine locations can be measured as rectilinear from the origin for an easy plotting of shop floor. The aisle of cells, machines, and the partitions are considered as per problem size. The centre passage aisle is allowed suitably related to sizes of part volume to be handled. Cell order and machine order are helpful in locating the cells and machines in shop floor and respective cells. 2D shop floor plans are prepared with the input of cell order, machine order and machine dimensions.

6. Managerial insights

This proposed similarity coefficient can do clear partitioning in block diagonal form if even size of the bench mark problem is large. So this similarity measure algorithm is suitable for any part volume which forms machine cells with no or few exceptional elements. Significance have 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 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 adjacent entries as origin. 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.

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 warehouse and storeroom as well as inventory for raw materials, the work-in progress.

7. Conclusions

Best clusters of machine cell and part family are simultaneously achieved compared to recent mathematical approaches to make use of floor area saving which is finally reducing human movements. The results of the optimization mathematical 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.

The performance evaluation is proved an effectiveness of the proposed P.A.R.I. model and the expectation is fulfilled that it is suitable for small and medium size formation Bench mark problems, with more grouping efficiency and considerably good for large size formation Bench mark problems with less percentage of exceptional elements, compared to other mathematical approaches. This approach proves through cell layout design as well as a linear programming model that this could be fitted to any size of part volume with less floor area. The outcomes obtained from this layout design are the floor area required by each cell and distances travelled by each job in and between cells.

Acknowledgements

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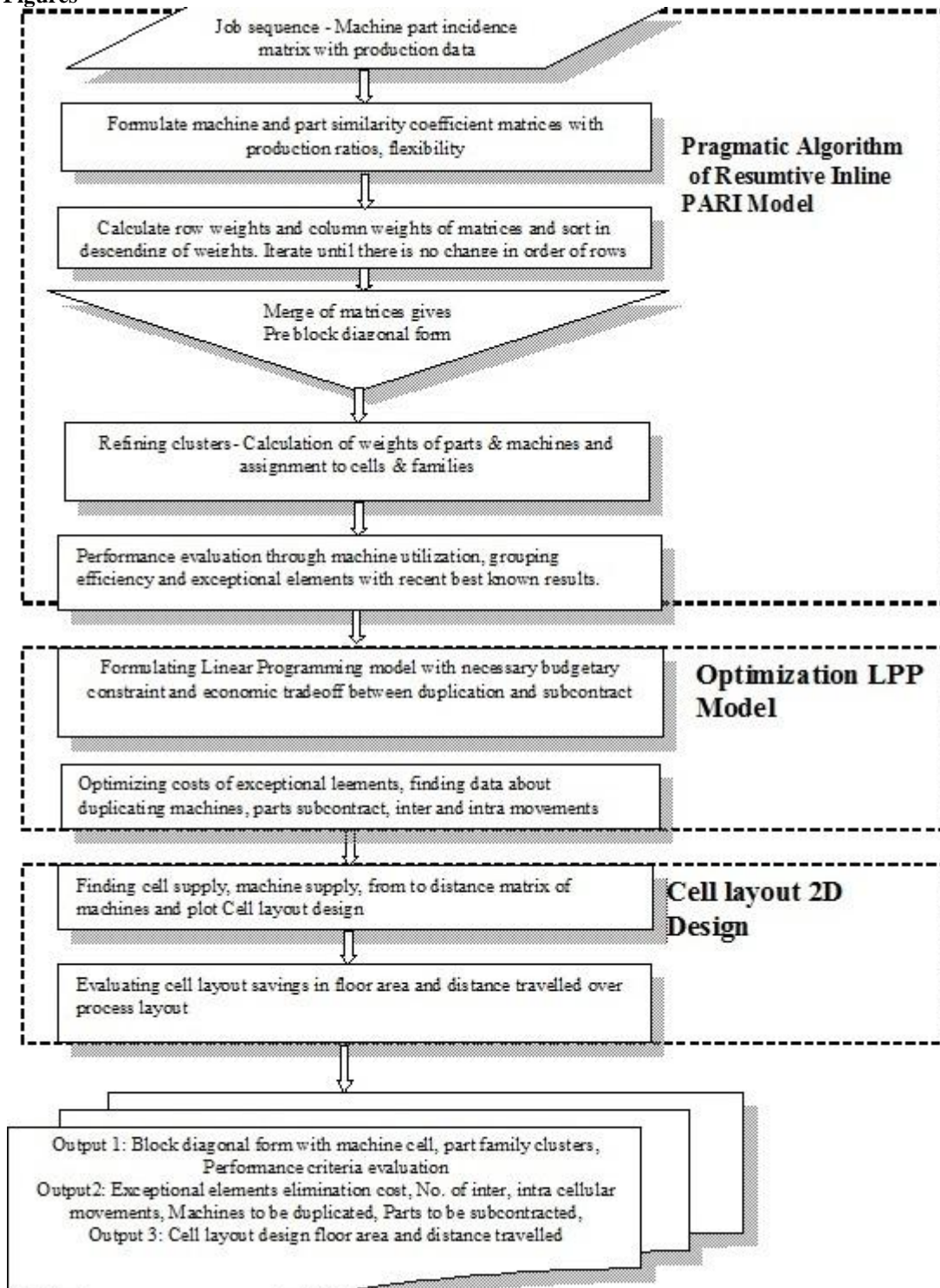


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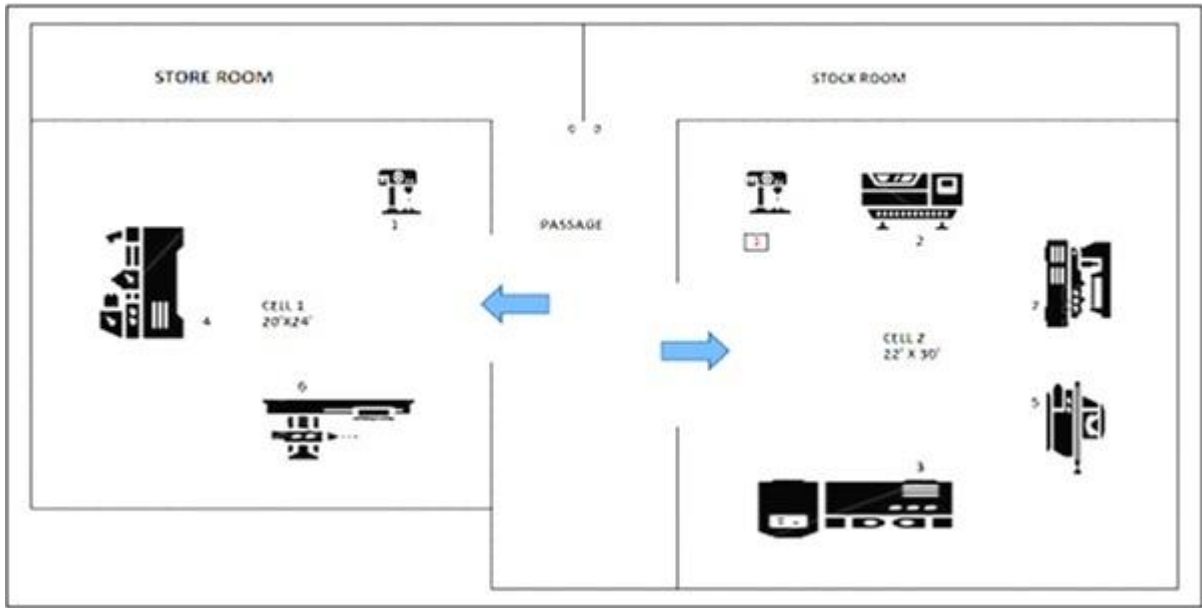


Fig.2 Cell layout design for Bench mark problem 1-7machines x 8 components Bench mark problem

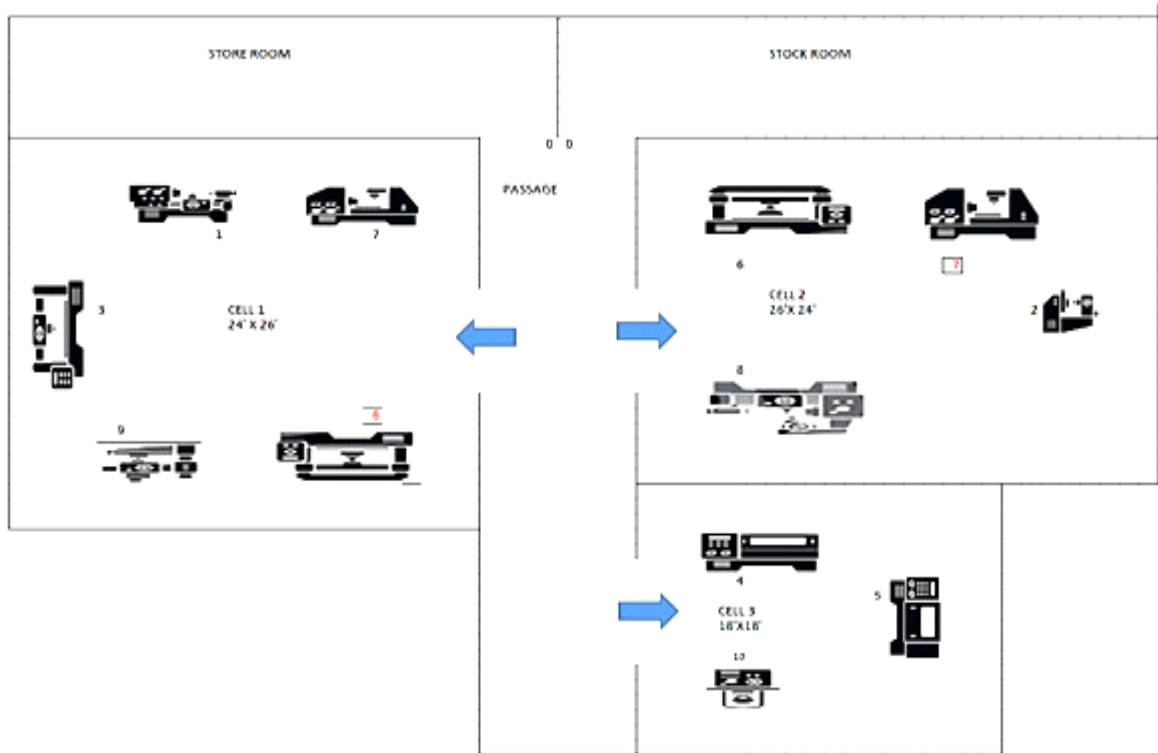


Fig.3 Cell layout design for Bench mark problem 2-10machines x 8 components Bench mark problem

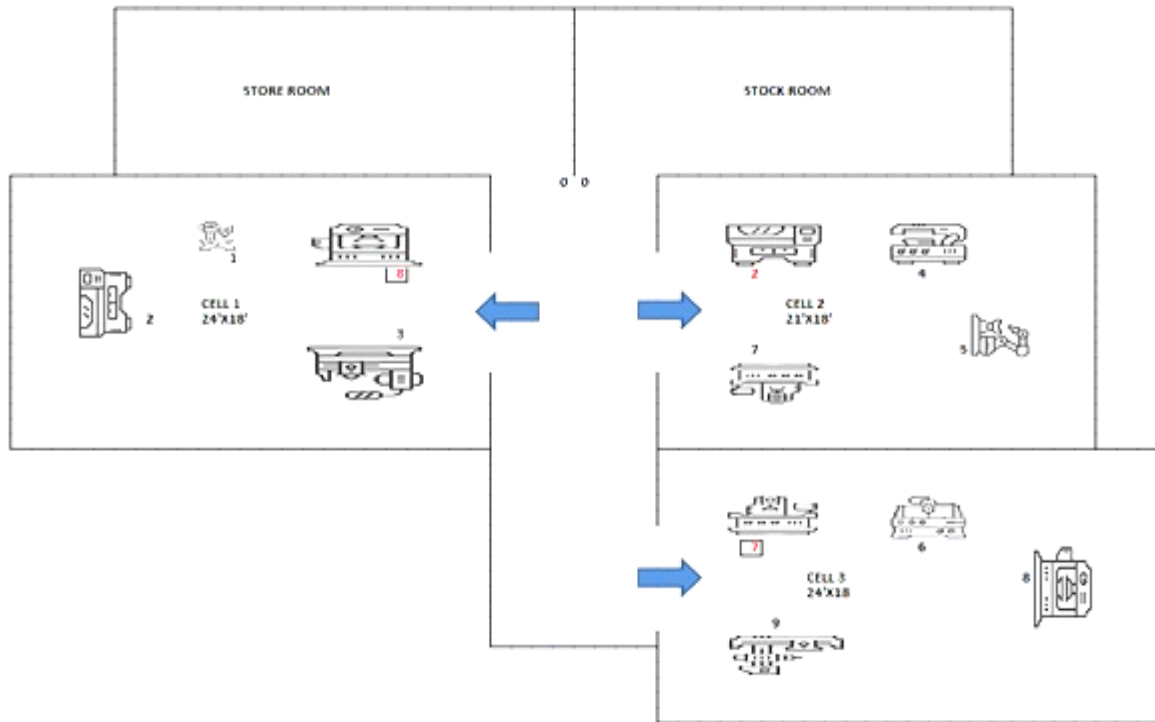


Fig.4 Cell layout design for Bench mark problem 3-9machines x 10 components Bench mark problem

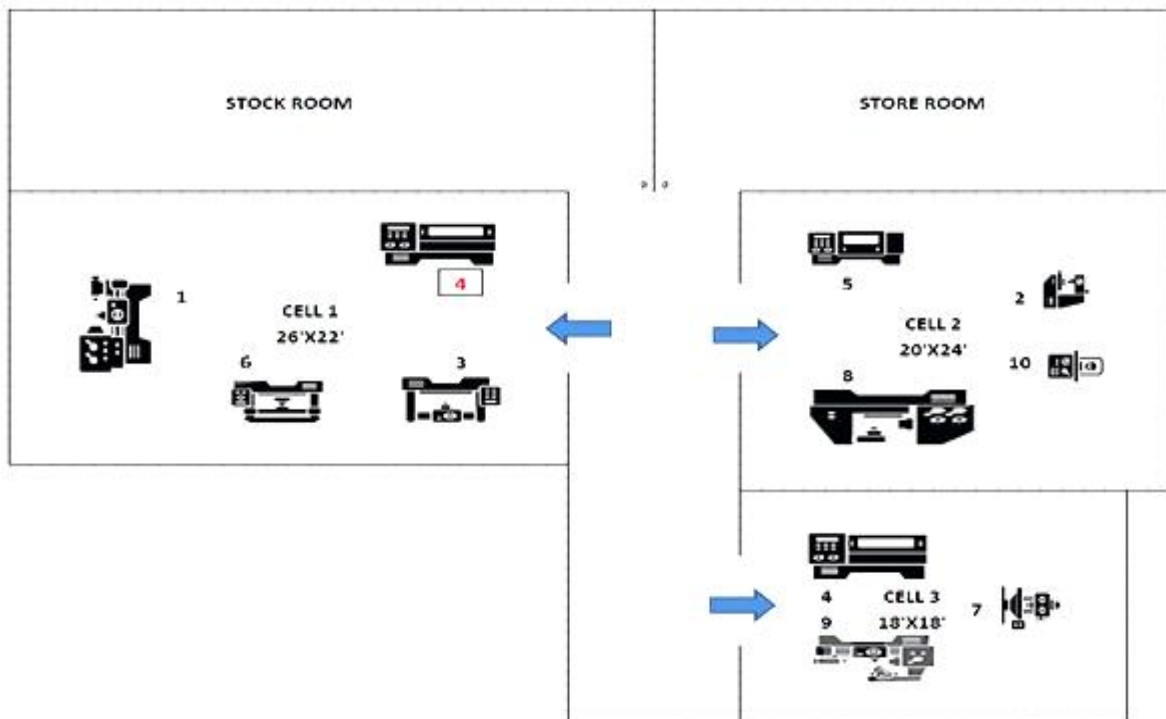


Fig.5 Cell layout design for Bench mark problem 4-10machines x 12 components Bench mark problem

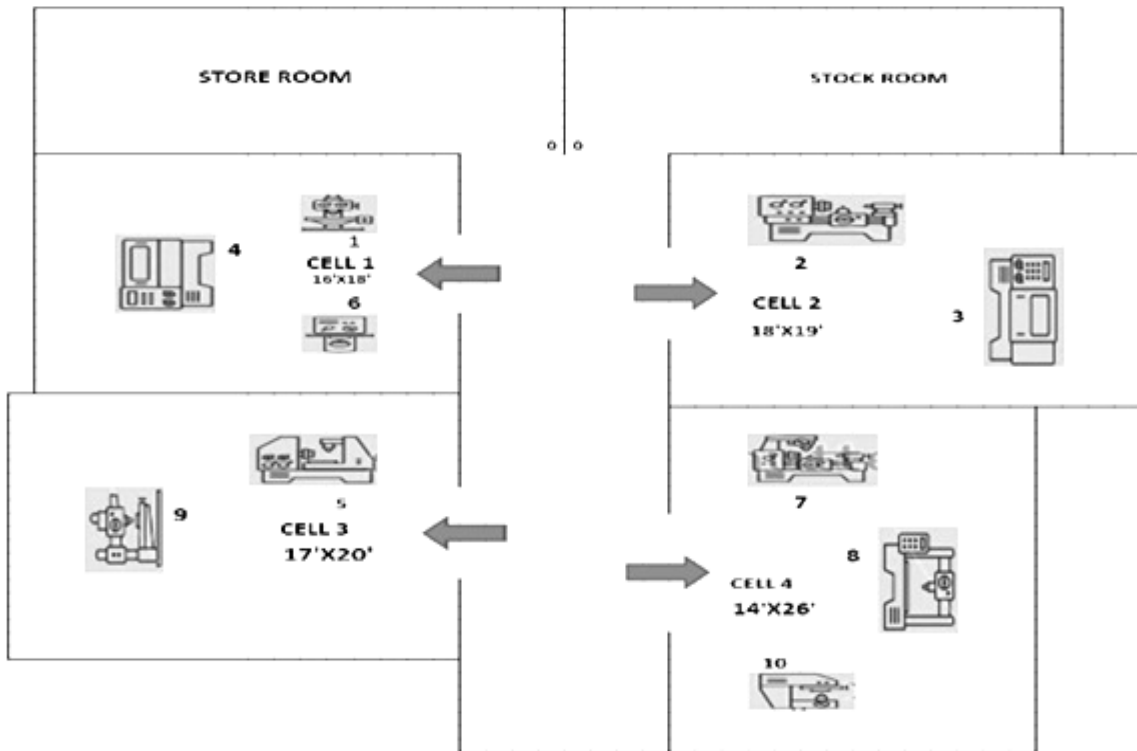


Fig. 6 Cell layout design for Bench mark problem 5 -10machines x 20 components Bench mark problem

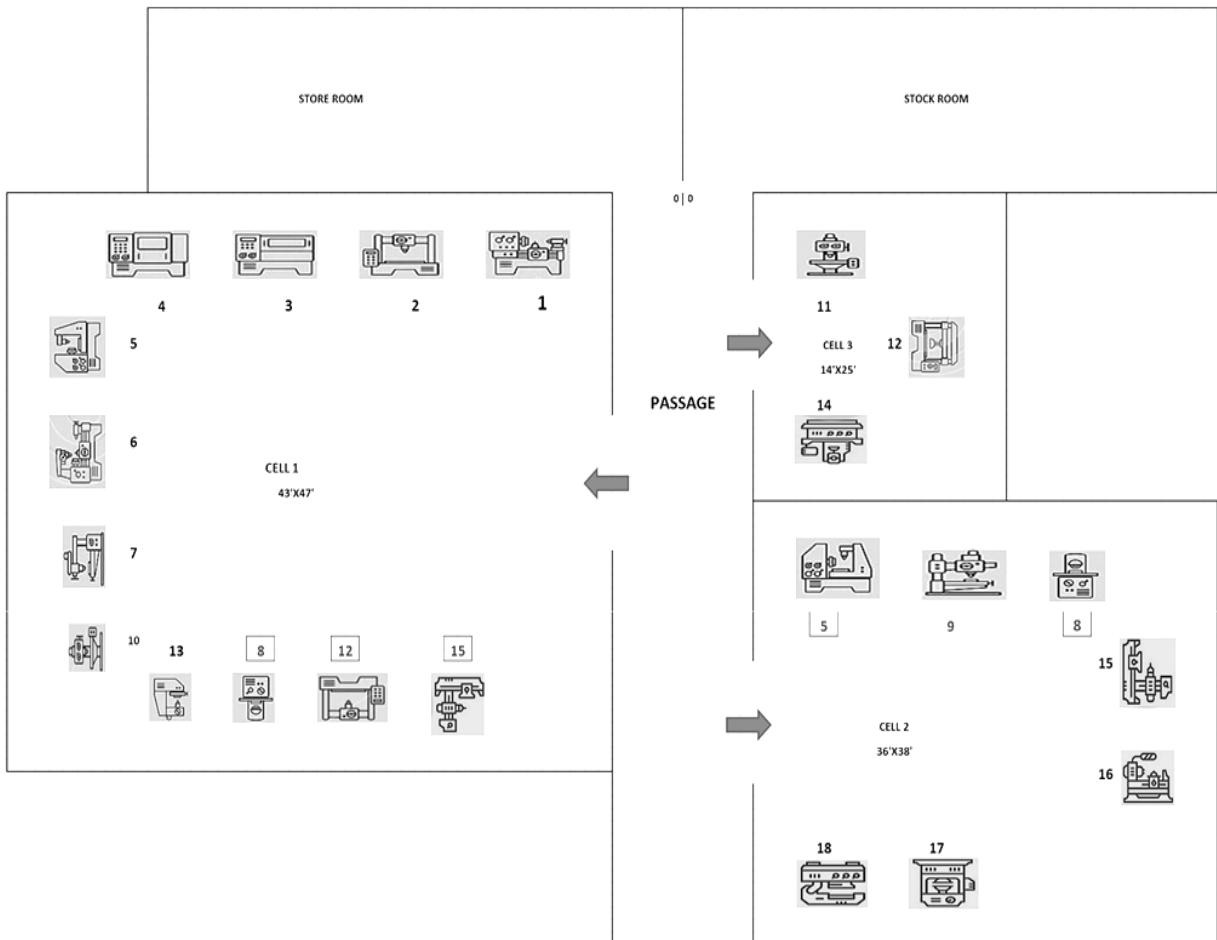


Fig.7 Cell layout design for Bench mark problem 6-18machines x 24 components Bench mark problem

Tables

Table1: Incidence matrix with production data. (Input Data from [25])

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	1

Table 3: Comparison of results – P.A.R.I. algorithm and other best-known approaches

Bench mark problem	Size m x c	No. of cells Nc	Proposed approach results, %			Best known results			Method, Literature Reference
			MU	GrE	PE	MU	GrE	PE	
1	7 X 8	2	80	80	12.5	88	68	26	Direct Cluster Algorithm.[4]
2	10 X 8	3	96	98	13	86.9	87	23	Heuristic GA Approach, [25]
3	9 X 10	3	90	68	27	88	67	27	Parametric model [2]
4	10X 12	3	83	82	10.5	83	81	10.5	Complete design model[14]
5	10x20	3	100	100	0	94	100	12	Flow matrix Algorithm[13]
6	18x24	3	53.3	65.0	21.5	31.0	53.6	38.6	Correlation. Analysis[27]

Table: 4 Computational results: LPP OPL Cplex model solutions

Bench mark problem	min Z ₹	Z _{ijk}	M _{ijk}	O _{ijk}	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)

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