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TIME-BASED MANUFACTURING IN WOOD FURNITURE PRODUCTION

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ABSTRACT

This paper presents the time-based manufacturing method that gives improved response capability in producing mixed wood furniture products. Production of the mixed products in the wood furniture industry can be detailed and complicated. The products include small lots of various models and designs including tables and chairs. In addition, the make-to-order strategy for supplying customer demand can present problems, leading to excessive production time and generate non-value added waste. Cellular Manufacturing System (CMS) is applied to the Furniture manufacturing shop floor to yield quick responses to manufacturing changes and to reduce lead time. Bond Energy Algorithm (BEA) and Complete Linkage Clustering (CLC) are used to form groups of parts and machines, and inter-and-intra-group movement is measured for the BEA or CLC selection. Consequently, the simulation models of the existing system and cellular manufacturing system are built.

Keywords : Time-based manufacturing, Wood furniture industry, Cellular Manufacturing

1 INTRODUCTION

In the competitive business environment today, many businesses focus attention especially on the rapidity for responding to their customers' needs. For this reason, continuous improvements are needed to increase response times to customer changes. One of the strategies is called Quick Response Manufacturing (QRM), which focuses on reducing lead-time in the whole process by eliminating Non Value-added Activity (NVA). The QRM production is focused on Cellular Manufacturing for the purpose of reducing lead-time in production and simplifying the production management.

There are many types of technical methodologies for lay-out planning on the production line and also various advantages and disadvantages. For example, Job Shop lay-out planning is the most flexible. When the product is manufactured it is usually built in a large batches, which are then routed through each of the processes where it queues up to be worked on before being moved to the next process. The job shop approach creates excessive work in process (WIP) and lengthy manufacturing lead times. The flow line approach is usually used for high production rates. A limitation of the flow line method is its lack of flexibility to produce products for which it are not designed. Cellular Manufacturing (CM) has emerged as the methodology for improving the productivity of manufacturing systems. This methodology offers a systems approach to the reorganization of the traditional complex job shop lay-out and flow line manufacturing systems into cellular or flexible manufacturing systems.

Cellular Manufacturing (CM) is the grouping of discrete multi-machines that produce parts families that are similar in geometry or sequence of process. The parts families can be built in the same cell from start to finish. CM has been proven to lower work in process levels, reducing production lead-time while retaining flexibility for new products.

In CM, there are many approaches for cell formation. Two approaches are compared here. The Array-based Clustering approach (Chu and Tsai,1990) for which The Bond Energy Algorithms (BEA) method is most effective. And the Similarity coefficient-based clustering approach (Gupta,1990), for which the Complete Linkage Clustering (CLC) is the most effective. In this paper a comparison of the two methods is made to determine the most effective approach. Inter-and-intra-group movement is the measured factor that is used to evaluate BEA and CLC. The most effective method is selected and used to build the simulation.

In order to apply the CM application to the problem characteristics of the wood furniture industry , this research uses a case study of wood furniture manufacturing for CM implementation. The case study compares results of simulation models between the traditional approach and the CM approach by measuring manufacturing lead times.

2 METHODOLOGY

The methodology in this paper starts with preparing the data into Part-Machine Matrix form, which is an important input for cell formation techniques; next, the same data set is calculated by CLC and BEA algorithms; after that, the results of both algorithms are evaluated and the most effective method is selected by Inter-and intra-group movement. From these results, an existing system simulation model and a CM system simulation model are built. The existing system simulation model is verified and validated. Both simulation models are run and evaluated in terms of manufacturing lead-time.

2.1 Bond Energy Algorithms

This algorithm was developed by McCormick, Schweitzer and White (1972) to identify and display natural variable groups or clusters that occur in complex data arrays. They proposed a measure of effectiveness (ME) such that an array that possesses dense clumps of numerically large elements will have a large ME when compared with the same array the rows and columns of which have been permutated so that numerically large elements are more uniformly distributed throughout the array (Nanua, 1996). The ME of an array is given by

$$\mathrm{ME(A)} = \frac{1}{2}\sum_{p=1}^{P}\sum_{m=1}^{M} a_{p,m}[a_{p,m+1} + a_{p,m-1} + a_{p+1,m} + a_{p-1,m}] \tag{1}$$

With

$$a_{0,m} = a_{p+1,m} = a_{p,0} = a_{p,m+1} = 0 \tag{2}$$

Where

$a_{p,m}$ = 1, if part p processing on machine m

= 0, others

Maximizing the ME by row and column permutations serves to create strong bond energies, that is
Maximize

$$\frac{1}{2}\sum_{p=1}^{P}\sum_{m=1}^{M} a_{pm}[a_{p,m+1} + a_{p,m-1} + a_{p+1,m} + a_{p-1,m}] \tag{3}$$

Where the maximization is taken overall P!M! possible arrays that can be obtained from the input array by row and column permutations. The above equation is also equivalent to

$$ME(A) = \sum_{m=1}^{M-1}\sum_{p=1}^{P} a_{pm} \cdot a_{p,m+1} + \sum_{p=1}^{P-1}\sum_{m=1}^{M} a_{pm} \cdot a_{p+1,m} \tag{4}$$

$$= ME(Rows) + ME(Columns)$$

Since the vertical (horizontal) bonds are unaffected by the interchanging the column (row), the ME decomposes to two parts: one finding the optimum column permutation, the other finding the optimum row permutation. A sequential-section suboptimal algorithm which exploits the nearest-neighbor feature as suggested by McCormick, Schweitzer and White (1972) is as follow.

Step 1.
Select part column arbitrarily and set i=1. Try placing each of the remaining (P-i) part columns in each of the (i+1) possible positions (to the left and right of the i columns already placed) and compute the contribution of each column to the ME.

$$ME(columns) = \sum_{p=1}^{i}\sum_{m=1}^{M} a_{pm} \cdot a_{p+1,m} \tag{5}$$

Place the column that gives the largest ME in its best position. In case of a tie, select arbitrarily. Increment i by 1 and repeat *i*=P. When all the columns have been placed, go to step 2.

Step 2.
Repeat the procedure for rows, calculating the ME as

$$ME(rows) = \sum_{m=1}^{i}\sum_{p=1}^{P} a_{pm} \cdot a_{p,m+1} \tag{6}$$

2.2 Complete Linkage Clustering

The data matrix which is cluster analyzed is the part-machine matrix. A similarity coefficient is first defined between two machines in terms of number of parts that visit each machine. Since the matrix has binary attributes, four types of matches are possible. A two-by-two table showing the number of 1-1, 1-0, 0-1, 0-0 matches between two machines is shown in Figure 1.

		Machine n	
		1	0
Machine m	1	A	B
	0	C	D

Figure 1: Definition of value

Where is A is the number of parts visiting both machine, B is number of parts visiting machine m and not n, C is number of parts visiting machine n and not m, and D is number of parts not visiting either machine.

Let Smn denote the similarity between machines m and n. To compute Smn, compare two machine rows m and n, computing the value of A, B, C and D. A number of coefficients have been proposed which differ in function of this value. The Jaccard coefficient is most often used in this context. This is written as:

$$S_{mn} = A/(A+B+C), 0.0 \le S_{mn} \le 1.0 \qquad (7)$$

The numerator indicates the number of parts processed on both machine m and n, and the denominator is the sum of the number of parts processed on both machines m and n and the number of parts processed on either machines m or n. The Jaccard Coefficient indicates maximum similarity when the two machines process the same part types, in which case B = C = 0 and Smn = 1.0. It indicates maximum dissimilarity when the two machine do not process the same part types, in which case A=0 and Smn = 0.0

When the similarity coefficients have been determined for machine pairs, CLC evaluate the similarity between two machines groups with the highest similarity are grouped together. This process continues until the desired machine groups have been obtained or all machines have been combining in one group.

Step 1
Compute the similarity coefficient S_{mn} for all machine pairs

Step 2
Find the minimum value in the resemblance matrix. Join the two machine groups (two machines, a machine and a machine groups or two machine groups). At each stage, machine group *n'* and *m'* are merged into a new group called t. This new group consists of all the machines in both groups. Add the new group t and update the resemblance matrix by computing the similarity between the new machine group t and some other machine group v as:

$$S_{tv} = \underset{\substack{met \\ nev}}{Max}\{S_{mn}\} \qquad (8)$$

Remove machine group *n'* and *m'* from the resemblance matrix. At each iteration the resemblance matrix gets eaten away by 1.

Step 3
When the resemblance matrix consist of one machine group, stop; otherwise go to step 2.

2.3 Inter-and-intra-group movement

Inter-and-intra-group movement is the evaluation method that is used to select the better solution by the cost of movement. Cost of movement in this method consists of inter movement cost and intra movement cost as:

$$COST = N_j C_1 + D_j C_2 \qquad (9)$$

By, N_j is the number of inter-group journeys for the *j*th solution, D_j is the total distance for the *j*th solution, C_1 is the cost of an inter-group journey, and C_2 is the cost per unit distance of an intra-group journey. The best solution is the one which gives minimum cost of movement. Because of cost of movements is affected by the location of machine groups and arrangement of machines within group. This distance can be estimated using CRAFT (Seiffodini and Wolf, 1987). However, since the sequence of operations has been ignored and typically each cell does not consist of many machines, it is reasonable to assume that the machines are laid out in random manner and compute the expected distance a part will travel based on a straight line layout, a rectangle layout or square layout (McAuley, 1972) The expected distance a part travels between two machines in a groups of M machines (D_j) is (M+1)/3 for a straight line, (R+L)/3 for a rectangle in case of *R* rows of *L* machines, and $2\sqrt{M}/3$ for a square (Irani , 1999).

2.4 Simulation

The Simulation model is built by Process Model Program - process flow animation computer program. The Process Model is presented in flow chart form. To build the model, many components are identified and assigned into the models. Those components are Entities, Activities, Arrivals and Routing by:

- **Entity**: Anything processed through the system such as raw-material, customer, document.
- **Activity**: A step in a process where some action is taken on an entity.
- **Arrivals**: Control how entities arrive from outside of system.
- **Routings**: Control how entities move from one activity or storage to another

After the model built, the next step is model verification and validation. Verification is the process of establishing that the computer program executes as intended and validation is the process of establishing that a desired accuracy or correspondence exists between the simulation model and the real system. In this study we verify the model in two ways. First, we compare the number of entity inputs and outputs and the second is comparison of manufacturing lead-time from the model and manufacturing lead-time from manual calculations. To validate, we compare between the model's work in process and real work in process by two sample t-test hypostasis checking. When the model is ready, the comparisons are made:

1. Compare Manufacturing Lead Time, Cycle Time and Value-Added Time between the existing model and the cellular model.
2. Forecasting manufacturing lead-time when order volume is increased by 2 and 4 times.
3. Measurement of total output and waste time by repeating customer orders every 40 and 120 hours.

In this simulation models include 4 types of time are as fo l-low:

1. Manufacturing Lead Time is the time from which the first entity is entered into the system until the last entity is out from the system.
2. Cycle Time is the total time an entity is used in the system.
3. Value Added Time is the time the system uses for adding value to entities.
4. Waste Time is the time the system used in which non-added value to entities.

By

Cycle Time = Value Added Time + Waste Time (10)

Value Added Time = Processing Time (11)

Waste Time = Queuing Time + Setup time
+ Moving Time (12)

From equation 10, 11 and 12

Cycle Time = Processing Time + Moving Time
+ Setup Time+ Queuing Time (13)

3 CASE STUDY

The methodology was applied to the wood furniture fac-tory that uses job shop layout, consisting of 22 different machine types. The 2 types of product are tables and chairs, which have 91 total parts. Almost all of the parts are manufactured by the same machines, and a part is processed through 5-10 steps before it is finished. The re-sult of the methodology is presented below.

3.1 Bond Energy Analysis (BEA) Result

Result from BEA is shown in Part Machine Matrix in Fig-ure 2; with 4 groups of machine, 4 groups of part family and 2 single machines.

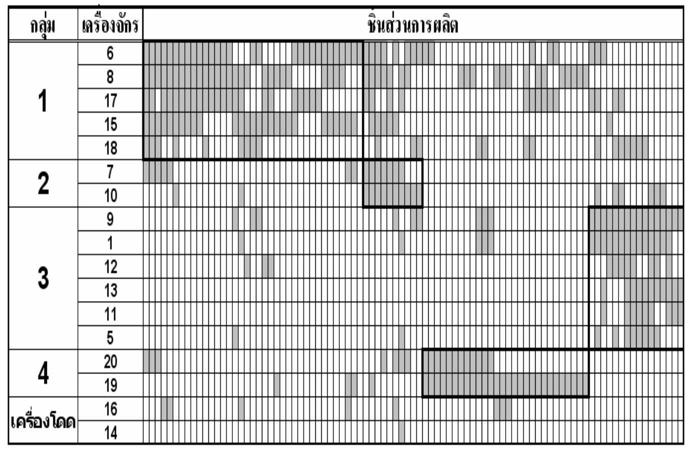

Figure 2: Part Machine Matrix result of BEA

3.2 Complete Linkage Clustering (CLC) Result

Dendrogram in Figure 3 indicate the result of CLC and that result can be show in Part-Machine Matrix in Figure 4 that resulted in 4 groups of machine , 4 groups of part family and 2 single machines.

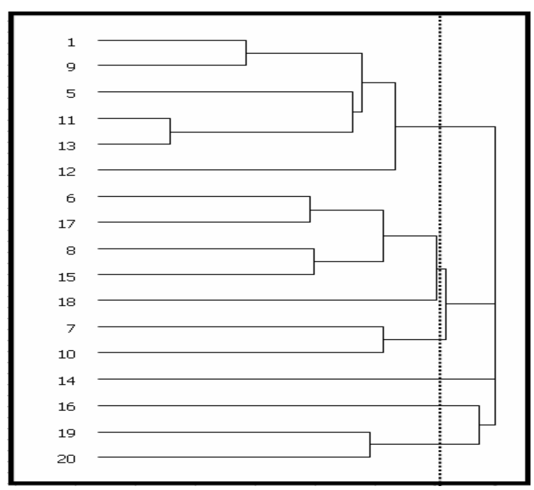

Figure 3 : Dendrogram Result from CLC

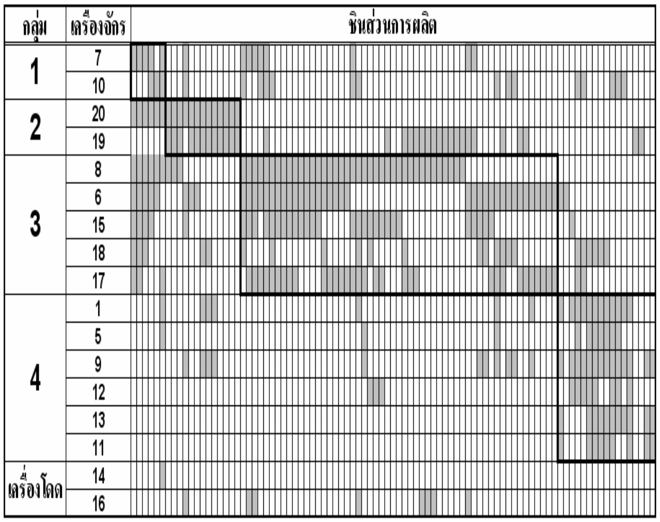

Figure 4: Part Machine Matrix result of CLC

3.3 Inter-and-intra-group movement result

The comparison of Inter-and-intra-group-movement result between CLC and BEA that show in table1

Table 1: comparison result between CLC and BEA

Algorithm	Inter-and intra-group Movement
CLC	2,757
BEA	2,041

From Table 1, the total movement cost of BEA is lower than CLC so BEA is better grouping algorithms for this environment. Therefore, BEA result is chosen to build cellular system model for analyzing in simulations.

3.4 Simulation Models

In the case study, real information from the factory is used to build the existing model and the cellular model. Many components are identified and assigned into the models by:

- **Entity**: Parts of products which break by Bill of Materials (BOMs).
- **Activity**: The machine which is used to produce those parts.
- **Arrivals**: Arrivals of parts which reach the systems.
- **Routings**: The steps of parts processing which show in terms of Operations Process Chart (OPC). Finally, components of time are assigned in to the models by:
  - **Processing Time** : Real processing time which has normal distribution behavior.
  - **Moving time** : Use default of the program.

For building the existing model, we identify and assign the model in job shop layout which includes 91 parts and 22 different types of machines. For building the cellular model, we identify the model from the results of BEA, because BEA gives the better solution. The machines are clustered into 4 cells. Single machines are assigned into cells according to experienced operator suggestions. The parts are clustered in to 4 groups and assigned to machine cells.

3.5 Simulations Results

By using Process Model to simulate these problems. The comparison between existing system and Cellular Manufacturing System is made.

- The results of the comparison in Manufacturing Lead Time, Cycle Time and Value-Added Time between the existing model and the cellular model is shown in Table 2.

Table 2: comparing of time between existing model and cellular model

Measurement	Existing Model	CM Model	Comparison Result
Total Cycle Time (Hours)	466.68	394.41	Reducing15.51%
Total Value Added Time (Hours)	194.66	194.03	Even
Waste Time(Hours)	272.02	200.38	Reducing 26.33 %
Mfg. Lead Time(Hours)	44.54	35.48	Reducing 20.34%

From Table 2, we can summarize that total cycle time is reduced 15.51 percent and waste time is reduced 26.33 percent. From equation 13, when processing time and setup time is fixed, moving time is not significant when it is compared with others. In conclusion, the reduction of total cycle time and waste time result from the reduction of queuing time.

- The result of forecasting manufacturing lead times while increasing order volume by two and four times is shown in Figure 5. This trend of manufacturing lead time at different order level is used to approximate time, when new order volume is coming, for responding to customers' needs and it also yields a more accurate due date.

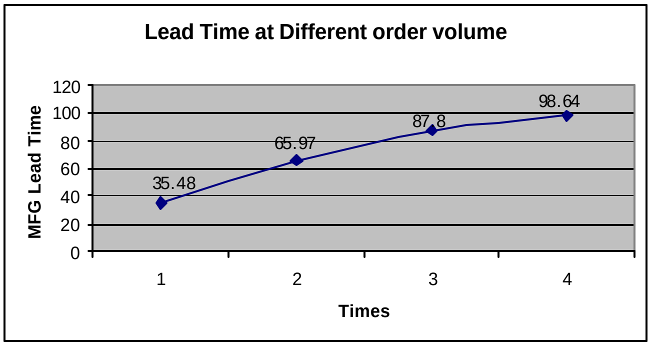

Figure 5: Lead time at different order volume

- The result of the experiment in total output and waste time by repeating the same amount of customer orders every 40 hours within 120 hours is shown in Table 3. From Table 3, the result indicates that the cellular system can increase output by 16.97 percent and reduce waste time by 4.36 percent in the same amount of production time. The increased output yields more utility of limitation resources.

Table 3: Result from simulations

Systems	Output (Pieces)	Waste Time (Hr.)
Existing	21,625	1,157.23
Cellular	26,045	1,106.78
Conclusion	Increasing 4,420	Reducing 50.45
	Increasing 16.97 %	Reducing 4.36 %

4 CONCLUSIONS

This paper has examined response improvement capability in the wood furniture industry by using Cellular manufacturing systems. Inter-and intra-group movement is used to evaluate the two clustering algorithms, BEA and CLC, that are the most effective algorithms in their class. Simulation models are built based on selected clustering algorithms. The existing system model and the cellular manufacturing system model are simulated and compared under different criteria.

The results of clustering indicate that BEA is more effective than CLC based on inter-and intra-group movement methods, which are evaluated in terms of moving cost.

The results from the simulation experiments indicate that the Cellular Manufacturing can reduce waste time by 26.33 percent and can reduce manufacturing lead-time by 20.34 percent. This leads to a faster response than the current system, by 9.06 hours. For this reason, the company is able to respond to the customers' needs more quickly. Cellular Manufacturing increases production plan accuracy, which yields more timely responses and a more competitive business ability.

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