Machine-Part Family Formation by Using ART-1 Simulator and FLEXY

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Group technology based manufacturing systems offer the advantages of flow production as well as the production flexibility of batch manufacturing. In this paper, by employing new clustering techniques, the part-machine spectrum of the manufacturing system and the relevant manufacturing process are analyzed according to design, similarity of machining and product flow. This leads to an organization of the production system into self-contained and self-regulating groups of machines called machine cells. Each machine cell undertakes a maximal production of a family of parts having similar manufacturing characteristics.

This paper carried out the ART-1 neural network approach in the analysis of the manufacturing similarity, and modified the basic approach to increase the efficiency of the classification procedure. Developed program packages ART-1 Simulator and FLEXY are used to create part families and machine cells within the group technology design.

Keywords: Group technology, ART-1 neural network, Simulation.

1. INTRODUCTION

Flexibility has bean the competitive thrust in the last ten years. This requires autonomous machines setup procedures and systems that have ability to get a good first part right for the first time. Flexibility necessitates integration, integration requires intelligence, and intelligence has to be backed up by real time control necessitating the design of adaptive and autonomous systems [2, 10].

The Intelligent Manufacturing Systems (IMS) are the strategic basis of the production engineering and the artificial neural networks (ANNs) as a part of intelligent technologies [8] have become an integral part of the IMS, with the key role in the design of autonomous manufacturing systems. The current trend is to build autonomous manufacturing systems that can adapt to changes in their environment [2, 8].

In this paper, the impact of ANNs in the group technology (GT) design is discussed. The underlying concept of GT is to bring together similar parts and related processes in order to take advantage of their similarities in both manufacturing and design [10]. The Adaptive Resonance Theory (ART) paradigm, which is a binary vector classifier, can be used for the solution of machine-part family formation problem (based on manufacturing simalarities identification). The ability of ART-1 neural network to categorize binary input vector into clusters [1, 2] can be exploited to solve the GT problem. Neural network based approach offers a viable alternative to solve the GT problem, with distinct advantages over the conventional approaches. The principal advantages of neural network based approaches as compared to traditional approaches [6] lie in ease of manufacturing similarity identification, computational performance and future new part assignment. In the elaboration of individual manufacturing processes designed group manufacturing procedure is used out of which the operations corresponding to the given part are singled out [3]. Group technology concept enables the optimization of the production and material flows, and thus decreases the price of the product [7].

The aim of this paper is to create part families and machine cells within the group technology design by using ART-1 neural network for the analysis of the manufacturing similarity and simulation of the part-machine spectrum of the manufacturing system based on program package FLEXY.

This approach has the generalization capability because the self-organizing neural networks (such as ART-1) can be used as classifiers. After training with a set of input patterns, these networks have the capability of identifying clusters of similar patterns in the set of input patterns [1, 2]. This property of ART-1 neural network is used to machine-part family formation.

The improved ART-1 approach incorporates a few changes in the basic approach [2, 4, 5, 10, 11]. The modified ART-1 approach, presented in this paper, also addresses the issue of obtaining optimal vigilance of variation in machine and part groups.

2. GROUP TECHNOLOGY

The group technology was introduced as early as in 1920 in the United States of America when Frederick Taylor supported the idea to classify the parts requiring special machine processing operations into the groups. So, group technology is a manufacturing philosophy that involves identifying and grouping components having similar or related attributes in order to take advantage of their similarities in the design and/or manufacturing phases of the production cycle [6]. Workpieces groups, or families, must be defined, and this can be done in one of three different methods [7]:

1. Design similarity grouping,
2. Similar production methods grouping, and
3. Coding.

Today's approach to the group technology concept implies the application of structured classification and the coding system based on the manufacturing similarity of workpieces. The problems in group classification, and thus the classification and coding of workpieces in the observed group are solved on the principles of the group technology design.

Manufacturing classification for group technology developed by the Production Engineering Department of the Mechanical Engineering Faculty in Belgrade [3, 4, 5, 11] is based on the following wholes:

1. Geometrical similarity of workpieces and the features surfaces to be machined,
2. Overall size of the rowmaterial and workpiece,
3. Accuracy concurrence of dimensions with the quality of machined surfaces,
4. Common manufacturing procedure based on manufacturing similarity,
5. Batch size, and
6. Type of the material.

This concept of group technology is a organizational approach which justifies small and medium batch sized production systems.

The principal advantages of a production system employing group technology lie in a substantially reduced work-in-process inventory and improved delivery performance because of reduced throughput time [3, 10]. The three general techniques of part family-machine group formation are [2, 6]:

1. Inspection,
2. Classification and coding, and
3. Production flow analysis (PFA).

3. ART-1 NEURAL NETWORK APPROACH

As this paper deals with the problem of group technology, particularly through manufacturing classification, self-organizing neural networks (like ART-1) were used in the research. The networks were based on competitive learning paradigms. After prior training of ANN with input patterns, they became able to identify the clusters of similar patterns with input pattern sets. This property of the self-organizing ANN is used in the paper to analyze manufacturing similarity, used as the basis for the machine-part family formation.

Artificial Neural Network ART-1 (Adaptive Resonance Theory) was introduced by Carpenter and Grossberg (1987) on the basis of the idea of coding and competitive learning [1, 2]. The mechanism of recurrent connections between the competitive and the input layer is used in ART-1 ANN for the retention of old when learning new information.The architecture of ART-1 neural network is given in Fig.1. Two main ART-1 neural network subsystems are the attentional subsystem and orienting subsystem. Attentional subsystem includes F_1 and F_2 layers which by activation of their neurons (nodes) create ANN associative conditions in short duration (Short Term Memory - STM) for each input pattern.
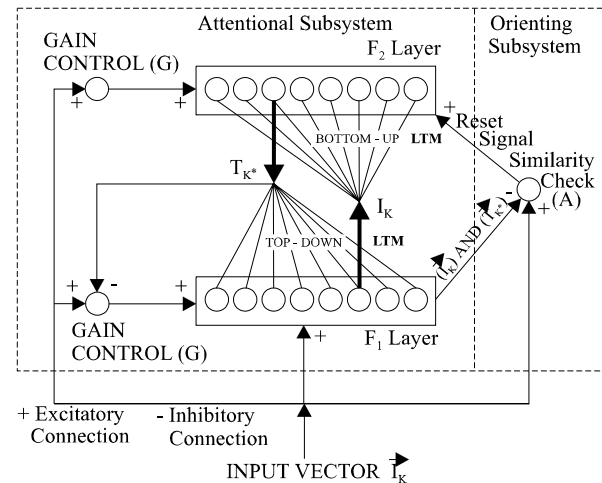

Figure 1. ART-1 System diagram

The weights associated with bottom-up and top-down connections between F_1 and F_2 are called Long Term Memory (LTM). These weights are the encoded information that remains a part of the network for an extended period. The orienting subsystem is needed to determine whether a pattern is familiar and well represented in the LTM or if a new class needs to be created for an unfamiliar pattern.

For each neuron in F_1 layer we have three possible input signals: input pattern (l_k), vector gain control signal (G) and the pattern created from F_2 layer (T_{k*}) and two output signals. The neuron in the F_1 layer becomes active when at least two, out of three possible, input signals are active ("2/3 rule"). As far as F_2 layer neuron is concerned there exists similar condition of input and output signals.

Input vector I_k is given in a binary form and the number of neurons in F_1 layer usually coincides with the input pattern dimensions. The connections between F_1 and F_2 layers are given through weight vector $W_j = [w_{1,j}, w_{2,j}, ... w_{p,j}]$. F_2 layer forms also a representative or an exemplar pattern $T_j = [t_{1,j}, t_{2,j}, ... t_{p,j}]$. When an input vector $I_k = [i_1, i_2, ... i_p]$ is presented at the F_1 layer of the ART-1 network, the gain vector G is initially set to $G = [1, 1, ... 1]$. The output neurons compete next with one another to respond to the input vector I_k, and the output neuron $k*$ which has the closest weight vector to the input vector identified as:

$$W_{k*} \cdot I_k = \max_{j \in 1,...,q} (W_j \cdot I_k). \qquad (1)$$

Dot product is used as the metric to identify the weight vector closest to the input vector.After identifying the output neuron $k*$, T_{k*} is fed back into the input layer, and if any of the T_{k*} components is '1', the gain vector G is then set to $G = [0, 0, ... 0]$. By the "2/3 rule" the output of the F_1 layer is then (I_k) AND (T_{k*}), a new vector, whose elements are obtained by applying the logical AND on the corresponding elements of the two vectors, giving the following estimate of the similarity between T_{k*} and I_k:

$$\text{similarity} = \frac{\text{number of 1s in } (I_k) \text{ AND } (T_{k*})}{\text{number of 1s in } I_k} . (2)$$

This similarity measure is compared with a prespecified threshold called the vigilance parameter ρ. If the computed similarity measure is greater than ρ, then the stored representative pattern associated with the output neuron $k*$ is changed to (I_k) AND (T_{k*}). The W_{k*} is also changed to:

$$w_{k*,i} = \frac{L \ c_i}{L - 1 + \sum_{i=1,...,p} c_i}, \qquad (3)$$

where c_i is the i-th component of (I_k) AND (T_{k*}), and L is the constant (usually set to 2). If the similarity is not greater than the prespecified vigilance parameter, then the output neuron with the next highest $W_j \cdot I_k$ is selected, and the same procedure is repeated.

3.1. Machine-part family formation by using ART-1

A number of clustering methodologies have been used to tackle the machine-part analysis problem, like rank order clustering (ROC) algorithm [2]. A brief description of ROC algorithm is presented in this section. ROC algorithm is used to diagonalized the initial machine-part incidence matrix. The machine-part family formation problem can be represented by the machine-part incidence matrix where element of matrix d_{ij} is '1' if part j is processed on machine i. The columns and rows of the machine-part incidence matrix, are binary vectors that can be applied as inputs to a neural network classifier. Column vectors can first be grouped to obtain an intermediate matrix and then, row vectors of this matrix can be grouped to obtain the final matrix. The ART-1 at first classifies the column vectors, based on their similarity. In the intermediate matrix, the similar columns are placed next to each other. This achieves a degree of clustering of the '1' elements of the matrix. In the next step, the row vectors, are applied as inputs to the ART-1 which likewise classifies them. Reordering the rows, such that similar rows are adjacent leads to the further clustering of the '1' elements resulting in the final matrix.

To show an example iteration (adopted from [2]), consider the following machine-part incidence matrix shown in Fig. 2. For the classification of the column vectors, column vectors 1 through 7 are presented sequentially at the input layer of the ART-1 neural network. Suppose W_1 and W_2 is initalized so that when $I_1 = [0\ 1\ 1\ 0\ 1]$ is presented, neuron 1 wins, that $I_1 \cdot W_1 > I_2 \cdot W_2$. In the first learning iteration there is no exemplar pattern stored at the output neurons, so I_l is stored as the exemplar pattern at neuron 1, and by using the weight change equations $W_1 = [0\ 0.5\ 0.5\ 0\ 0.5]$. Now when next column vector $I_2 = [1\ 0\ 1\ 1\ 0]$ is presented, there are the following two cases depending on the initial value of W_2.

<u>Case 1</u>. If we assume that $I_2 \cdot W_1 > I_2 \cdot W_2$, then (I_2) AND (T_1) is compared against the stored vector at the output neuron 1.
(I_2) AND $(T_1) = [1\ 0\ 1\ 1\ 0]$AND $[0\ 1\ 1\ 0\ 1] = [0\ 0\ 1\ 0\ 0]$ and the similarity, Eqn.(2), measure between I_2 is computed as

$$\text{similarity} = \frac{\text{number of 1s in } (I_2) \text{ AND } (T_1)}{\text{number of 1s in } I_2} = \frac{1}{3} = 0.333$$

If the prespecified vigilance parameter ρ is less than 0.333, then the pattern is associated with the first neuron, and T_1 changes to $[0\ 0\ 1\ 0\ 0]$ and W_1 is also changed using the weight change equations. In the opposite case ($\rho_2 = 0.333$), T_1 and W_1 are not changed, and the vector I_2 is used to create the initial exemplar at neuron 2.

<u>Case 2</u>. Assuming that $I_2 \cdot W_1 < I_2 \cdot W_2$, then the vector I_2 is used to create an initial exemplar at neuron 2.

		p a r t s						
		1	**2**	**3**	**4**	**5**	**6**	**7**
	1		1		1	1	1	
	2	1		1				
m a c h i n e s	**3**	1	1					1
	4		1		1		1	
	5	1						1

Figure 2. Initial matrix

These iterations are repeated by presenting the input vectors one at a time, until the weight vectors show no change with further training iterations. The part groups can be identified by observation of the output activations, that is, the winning neurons, and all part vectors cause a particular output unit to respond or win are classified as a part family.After grouping the columns with $\rho_1 = 0.4$ (by using program package "ART-1 Simulator") the resulting matrix is shown in Fig. 3.

In addition to this, for the purpose of calculating data such as the component average flow-time, the percentage of tardy jobs, the average tardiness, the machine idle-time, and machine engaged-time must also be collected. Cellular manufacturing cells, in particular, represent a complex system for study as they involve subfamilies of the part families which wait for processing at work centres [12]. The present work aims at analysing the effects of different group scheduling heuristics and also their effects on the performance measures of a cell. Hence, FLEXY simulation system [13, 14] is used.

parts

machines	1	3	2	4	5	6	7
1			1	1	1	1	
4			1	1		1	
2	1	1					
3	1	1					1
5	1						1

Figure 3. Final matrix using ART-1 (solution 1)

There are three part families formed (Fig.3):

Part family 1: Parts 1, 3

Part family 2: Parts 2, 4, 5, 6

Part family 3: Part 7.

Next, the row vectors are classified using program package "ART-1 Simulator" with vigilance parameter $\rho_2 = 0.4$, while the machine groups obtained are:

Machine group 1: Machines 1, 4

Machine group 2: Machine 2,

Machine group 3: Machines 3, 5.

The same procedure is repeated for a different set of vigilances of $\rho_1 = 0.3$ and $\rho_2 = 0.3$, and the new final matrix obtained is shown in Fig. 4.

parts

machines	1	2	7	4	5	6	3
1		1		1	1	1	
4		1		1		1	
2	1						1
3	1	1	1				
5	1	1					

Figure 4. Final matrix using ART-1 (solution 2)

The part families obtained are

Part family 1: Parts 1, 2, 7

Part family 2: Parts 4, 5, 6

Part family 3: Part 3

while the machine groups obtained are

Machine group 1: Machines 1, 4

Machine group 2: Machines 2, 3, 5.

Software package "ART-1 Simulator", based on the architecture of ART-1 neural network, is developed for the machine-part family formation within the group technology design. Software is developed in Visual Basic [9], and main windows are presented in Fig. 5.

4. EXPERIMENTAL COMPARISON

Simulation is best suited to the systems that involve large amounts of data to be handled, manipulated and analysed. Scheduling in production systems involves a

Figure 5. Working environment of the ″ART-1 Simulator″

4.1. Basic assumptions

In carrying out simulation experiments, the following basic assumptions are adopted:

a) Customer orders arrive in random order

b) The shortest processing time (SPT) priority rule is adopted

c) It is assumed that processing times for all five machines are identical. Setup time is calculated to be multiple factor of processing time. The multiple factor is 0.5.

4.2. Simulation results

Simulation runs were performed for two solutions for cell formation. Screen shots from FLEXY simulation system showing layouts for solution 1 and solution 2 are shown in Fig. 6 and Fig. 7 respectively.

Two performance measures are considered when comparing the solutions: total processing time and utilization of machines and automated guided vehicle (AGV).

Results of simulation runs are shown in Table 1. As it can be seen from the table better results are obtained for solution 2. Thus it is proved that solution 2 is optimal solution.
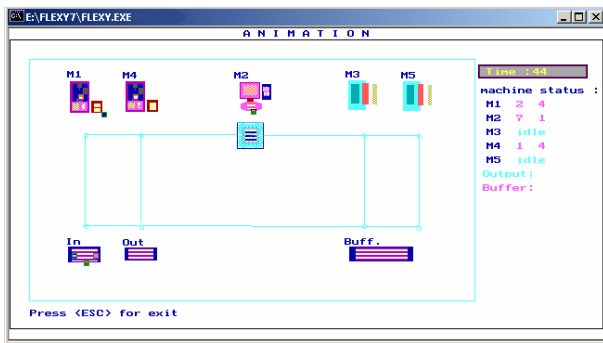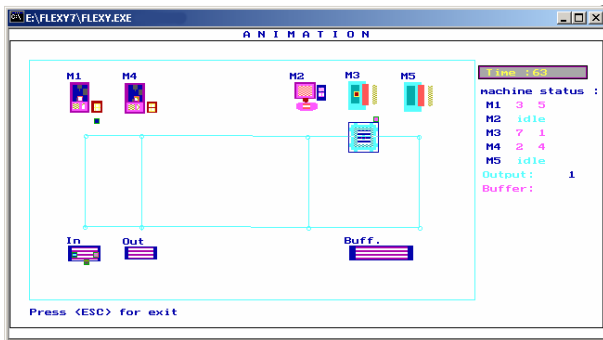
Figure 6. Simulation layout for solution 1

Figure 7. Simulation layout for solution 2

Table 1. Simulation results

		Solution 1	Solution 2
Utilization of machine	1	86	99
	2	43	50
	3	65	74
	4	65	74
	5	43	50
Utilization of AGV		35	29
Total processing time		4645 min	4033 min

5. CONCLUSION

For a realistic size problem with, for example, 1500 parts and 110 machines, ART-1 Simulator and FLEXY can be used to solve this large scale group technology problem, by using the same procedure, presented in the paper. The vigilance parameter has an important role and the optimal value selected is based on the number of machine cells in part families formed. ART-1 approach, described in this paper, demonstrates the power of artificial neural networks over classical solution approaches.

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ФОРМИРАЊЕ ФАМИЛИЈЕ МАШИНЕ-ДЕЛОВИ КОРИШЋЕЊЕМ СОФТВЕРА *ART-1 SIMULATOR* И *FLEXY*

Зоран Миљковић, Бојан Бабић

Технолошки системи базирани на концепту групне технологије имају предности, пре свега у домену флексибилности. У раду је, увођењем нове технике кластеровања, анализиран однос фамилије машине-делови унутар технолошког система и релевантних

технолошких процеса, с обзиром на технолошку сличност делова који чине фамилију. Такав технолошки систем се организује у групе машина, формирајући ћелије, уз обезбеђену максималну производност делова.

Рад презентира нову примену ART-1 вештачке неуронске мреже у анализи технолошке сличности и нуди модификован базични приступ у циљу повећања ефикасности процедуре класификовања. Развијени софтвери ART-1 Simulator и FLEXY су коришћени у поступку формирања фамилија, сходно реафирмисаном концепту пројектовања групне технологије.