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MULTI OBJECTIVE SCHEDULING OF JOBS, AGVs AND AS/RS IN FMS USING ARTIFICIAL IMMUNE SYSTEM

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Abstract:
The success of any FMS lies in the design of an appropriate scheduling procedure to optimize the required performance measures of the manufacturing systems. This article addresses the problem of simultaneous scheduling of jobs, Automated Storage and Retrieval Systems (AS/RS) and two identical Automated Guided Vehicles (AGVs) in a Flexible Manufacturing System (FMS). It deals scheduling with multiple and competing objectives of FMS and optimized by employing a non-traditional optimization technique called Artificial Immune System (AIS) to generate optimal schedules. The problem considered here is a large variety problem (16 machines and 43 parts) and the multiple objectives considered are minimizing penalty cost, minimizing machine idle time and minimizing the distance travelled by the Storage/ Retrieval (S/R) machine. To prove the performance of proposed algorithm a series of computational experiments are done and a good results are obtained.

Keywords: FMS Scheduling, Multi objective function, Artificial Immune System

1. INTRODUCTION

Flexible Manufacturing System (FMS) is a highly sophisticated manufacturing system to meet customer's requirements. The FMS fills up the gap between the traditional job shops and highly automated transfer lines. This kind of system is very useful to achieve high productivity and flexibility. The problems in FMS are generally classified into Design, Planning, Scheduling and Control. This work is primarily concerned with the scheduling problems of FMS.

In FMS scheduling, the sub-systems like material handling systems, storage and retrieval system, etc. should be considered and also decisions should be taken when the system is in operation. In scheduling problems of FMS, the jobs that are going to various Computer Numerical Control (CNC) machines, Automated Guided Vehicles (AGVs) and Automated Storage and Retrieval System (AS/RS) are scheduled simultaneously.

The non-traditional optimization techniques have been also employed for various engineering application problems due to their robustness and convergence to global optima. Sridhar and Rajendran [1] applied GA to part family grouping and parts scheduling within the part families in a flow line based manufacturing cell with the objectives of minimizing the makespan and total flow time had been jointly considered. Gunduz Ulusoy et al [2] implemented GA algorithm for simultaneous scheduling of machines and AGVs in an FMS consisting of several machining centers and one or more identical AGVs. The objective was minimization of makespan.

Taghaboni and Tanchoco [3] dealt the routing techniques of AGVs. Jawahar et al [4] linked the operation of the AS/RS with the production schedule and used GA to improve the performance of the AS/RS operation by allocating the materials with minimum movement of the shuttle. Ponnambalam et al [5] proposed a multi-objective evolutionary search algorithm using a travelling salesman algorithm and genetic algorithm for flow-shop scheduling. The proposed algorithm used a weighted sum of multiple objectives that included minimization of makespan, mean flow time and machine idle time. Kim et al [6] proposed an integrated approach of inductive and competitive neutral methods for developing a multi-objective FMS

schedules. Engin and Alper Doyen [7] introduced a new approach to solve hybrid flow shop scheduling problems by artificial immune system for the future generation computer systems and the AIS algorithm is already used in different applications namely computer and network security [8, 9], fault and anomaly detection [10, 11], optimization [12, 13], data analysis and data mining [14, 15] and flow shop scheduling where AIS produced better results.

2. PROBLEM DESCRIPTION

The problem environment and assumptions [16] of the present work deals with multiple objective functions for Jobs, AGVs and AS/RS are detailed as follows:

(i) The FMS considered in this paper has the configuration as shown in Figure 1.

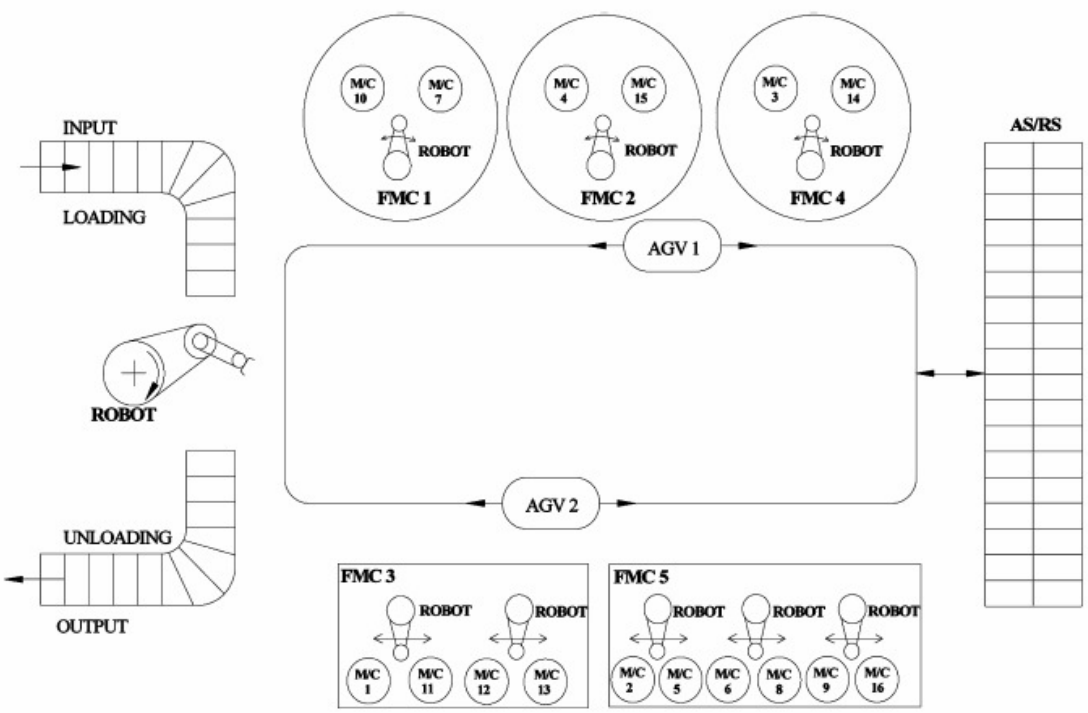

Figure 1: Configuration of the FMS.

- There are five Flexible Machining Cells (FMCs) each having two to six Computer Numerical Control machines (CNCs) each with an independent and self sufficient tool magazine and one Automatic Tool Changer (ATC) and one Automatic Pallet Changer (APC). Each cell is supported by one to three dedicated robots, for the intra-cell movement of materials between operations.
- There is a loading station from where the parts are released in batches for manufacturing in the FMS.
- There is an unloading station from where the finished parts are collected and conveyed to the finished storage.
- There is one Automatic Storage and Retrieval System (AS/RS) to store the work in progress.
- The five FMCs are connected by two identical Automated Guided Vehicles (AGV). These AGVs perform the inter cell movements between the FMCs and the movement of loaded pallets from the loading station to any of the FMCs and the movement of finished product from any of the FMCs to the unloading station and the movement of semi finished products between the AS/RS and the FMCs.
- There is a dedicated robot for loading and unloading AGVs.

(ii) The assumptions made in this work are:

- The FMS operation caters to a pure job shop environment handling 40 to 50 varieties of products with a particular combination of tools in the tool magazines. The machine cells and part families, as shown in the Table I, are optimum with respect to minimum handling and backtracking. FMC No. 5 is a remainder cell catering for all the possible exceptional elements in the machine-part incident matrix. The heuristic developed for the fractional cell formation [17] is employed to obtain this cell-part family configuration.

Table I: Part families and machine cells configuration.

FMC number	Machine numbers	Part family (Jobs)
1	7,10	(1,8,10,12,13,25,26,31,38,39,42)
2	4,15	(4,5,14,15,18,19,21,23,29,33,41)
3	1,11,12,13	(3,9,11,16,20,22,24,27,30,37,43)
4	3,14	(2,6,7,17,28,32,34,35,36,40)
5	2,5,6,8,9,16	FMC 5 is a remainder cell

- Each type/variety has a particular processing sequence, batch size, due date and penalty cost for not meeting the due date. The processing sequence is based on the optimum route with respect to minimum manufacturing lead-time.
- Each processing step has a processing time on a specific machine.
- There is no constraint on the availability of pallets, fixtures, AGVs, robots, AS/RS etc.

A random product-mix generated is shown in the Table II.

(iii) In the real time environment it becomes imperative to optimize concurrently several incommensurable and competing objectives. The business environment usually drives operational executives in prioritizing the objectives and the priorities often change. These objectives are set ultimately to improve the overall productivity and the efficiency of the system. However the primary objective remains to maximize the utilization of the capital-intensive system. With the emerging trends towards customer orientation in the world of global market the system cannot afford to ignore objectives that have a direct relation to customer satisfaction. This is also considered as one of the objectives. The minimum movement of Storage/Retrieval (S/R) machine also considered as another objective.

Table II: Product mix with due date and penalty cost.

Job no.	Processing Sequence – (Machine No. & processing time in mins.)	Due date (days)	Batch size (No.)	Penalty cost (Rs./units/day)
1	{6,1},{7,1},{8,1},{10,2}	17	150	1.00
2	{2,1},{6,1},{8,1},{9,2},{14,4},{16,2)	17	200	1.00
3	{8,1},{11,3},{13,4}	14	800	1.00
4	{9,4}	26	700	2.00
5	{4,5},{5,3},{15,4}	11	150	1.00
6	{6,5},{14,1}	16	700	1.00
7	{3,5},{6,3},{16,5}	26	250	2.00
8	{5,4},{6,5},{8,1}	26	850	2.00
9	{4,1},{5,5},{8,1},{11,1}	1	100	0.00
10	{2,2},{9,1},{16,4}	20	150	2.00
11	{8,4},{12,2}	1	250	1.00
12	{6,2},{8,4},{10,1}	19	1000	3.00
13	{6,1},{7,5},{10,4}	25	700	4.00
14	{4,2},{5,3},{6,2},{15,2}	22	1000	4.00
15	{5,4},{8,3}	15	700	5.00
16	{5,3}	27	750	3.00
17	{3,1},{6,4},{14,1}	20	650	4.00
18	{9,2},{16,3}	24	250	5.00
19	{4,1},{5,5},{6,2},{8,2},{15.5}	5	450	1.00
20	{8,2},{11,4}	11	50	5.00
21	{4,5},{5,5},{6,2},{8,2},{15,5}	16	850	3.00
22	{12,5}	24	200	5.00
23	{4.2},{5,1},{6,5},{8,4}	14	50	4.00
24	{8,4},{11,4},{12,5},{13,4}	7	200	5.00
25	{7,3},{10,2}	24	350	1.00
26	{10,2}	27	450	0.00
27	{8,5},{11,5},{12,4}	22	400	1.00
28	{2,1},{8,1},{9,2}	3	950	5.00
29	{4,1},{5,5}	7	700	1.00
30	{11,3},{12,5}	18	1000	1.00
31	{8,2},{10,2}	2	800	2.00
32	{2,3},{6,4},{9,3}	15	800	1.00
33	{5,4},{6,5},{15,3}	27	500	4.00
34	{3,2},{6,2}	12	300	4.00
35	{3,4},{14,1}	9	900	2.00
36	{3,2}	20	700	2.00
37	{1,5},{2,2},{6,3},{8,3},{9,2},{16,4}	22	250	4.00
38	{2,4},{8,3},{9,2},{16,5}	8	50	1.00
39	{6,5},{10,5}	9	500	1.00
40	{2,2},{6,4},{9,4}	7	250	5.00
41	{5,1},{8,2},{15,1}	22	800	4.00
42	{2,5},{6,4},{9,3}{16,1}	19	400	2.00
43	{1,3},{5,2},{6,2},{8,2},{15,3}	15	550	3.00

(iv) The structure of the AS/RS considered in this work is shown in Figure 2.

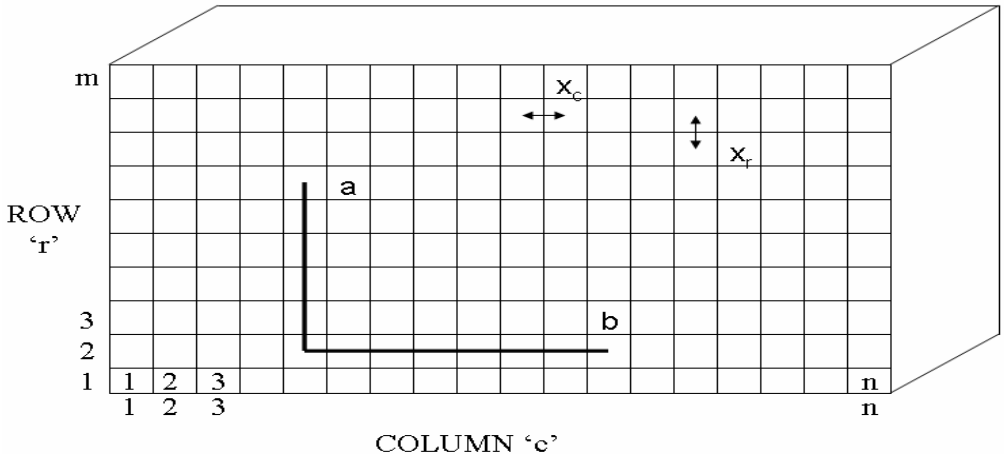

Figure 2: AS/RS structure.

The storage structure considered is rectangular with 'm' rows and 'n' columns.

- Each cell is capable of holding one item of any type. The centre distance between any two adjacent cells in a row is Xr and in a column is Xc.
- The numbers given inside the cell indicate the address of the storage location.
- There is one shuttle of the crane type, which is capable of moving vertically and horizontally.
- The Pickup and Deposit (P&D) station is at the lower left hand corner of the aisle.

In this AS/RS, Storage and Retrieval (S/R) machine movement is a major decision parameter for its operation and control. The distance travelled by the S/R machine, when it moves from address a to b to complete one activity, is calculated by the following two steps:

Step1: Identification of row and column number:

A simple algebraic equation can be used to ascertain the row and column numbers of the attributed address of the storage location. For example A is the address of the storage location and its algebraic equation takes the form:

$$A = \text{quotient} * \text{divider} + \text{remainder} \quad (1)$$

where divider is equal to number of columns n, then:

$$\text{Column number } A_c = \begin{cases} \text{reminder} & \text{if reminder} \neq 0 \\ \text{reminder}+1, & \text{if reminder} = 0 \end{cases} \quad (2)$$

$$\text{Row number } A_r = \begin{cases} \text{quotient}+1 & \text{if reminder} \neq 0 \\ \text{quotient}, & \text{if reminder} = 0 \end{cases} \quad (3)$$

Step2: Distance calculation for the movement from *a* to *b.*

As per the AS/RS structure shown in Figure 2, the distance between two storage locations a and b can be calculated using general formula:

$$\text{Distance} = P + X_r * (\text{mod}\ (a_r - b_r)) + X_c * (\text{mod}\ (a_c - b_c)) \quad (4)$$

Where

P – Distance from P&D station to First storage cell.

X_r & X_c – Centre distance between two adjacent cells in a row & column respectively,
a_r, b_r - Distance between the locations '*a*' and '*b*' row wise
a_c, b_c - Distance between the locations '*a*' and '*b*' column wise

2.1 Combined Objective Function (COF)

The objective function can be defined mathematically as follows:

$$\text{Minimize COF} = W_1 \times (X_p \div MPP) + W_2 \times (X_q \div TE) + W_3 (X_t \div MPD) \quad (5)$$

Where,

X_p = Total penalty cost incurred

$$X_p = \sum_i (CT_i - DD_i) \times UPC_i \times BS_i$$

i = Job number
X_t = Total distance traveled by S/R machine
CT_i = Completion Time of job i
DD_i = Due Date for job i
UPC_i = Unit Penalty Cost for job i
BS_i = Batch Size of job i
MPP = Maximum Permissible Penalty
MPD = Maximum Permissible Distance traveled by S/R machine
W_1 = Weightage factor for Customer satisfaction = 0.4
W_2 = Weightage factor for Machine Utilization = 0.3
W_3 = Weightage factor for AS/RS Utilization = 0.3
X_q = Total Machine Down Time

$$X_q = \sum_j MD_j$$

j = Machine number:

$$MD_j = TE - \sum_i PT_{ji} \quad (6)$$

TE = Total Elapsed Time
PT_{ji} = Processing Time of i^{th} job with j^{th} machine:

Makespan by considering AGV's time = $\sum \{\sum$(Actual machine time of job + Distance travelled by AGV[i] / Speed AGV[i])$\}$ (7)

i = 1 and 2

In this work, weightages are given as W_1= 0.4, W_2= 0.3 and W_3 = 0.3. However different ratios can be applied to them according to the demand of business situation.

Assumptions:

(i) After completion of single job every AGV must come to START position.
(ii) Distance between two machine cells is taken as 6 meters.
(iii) Speed of each AGV is considered as 100 m/min.

3. ARTIFICIAL IMMUNE SYSTEM (AIS)

The operative mechanisms of immune system are very efficient from a computational standpoint [8]. Table III represents the comparison between the immune system and immune algorithm.

Table III: Comparison between the immune system and immune algorithm.

Immune System	**Immune Algorithm**
Antigen	Problem to be solved
Antibody	Best solution vector
Recognition of antigen	Identification of the problem
Production of antibody from memory cells	Recalling a past successful solution
Lymphocyte differentiation	Maintenance of good solutions (memory)
T-cell suppression	Elimination of surplus candidate solutions

AIS were built on the two principles of the immune system namely clonal selection principle and Affinity maturation principle.

3.1 Cloning selection principle

The clone selection principle, or theory, is the algorithm used by the immune system to describe the basis features of an immune response to an antigenic stimulus, as shown in Figure 3. Each schedule has a makespan value that refers to the affinity value of that antibody. Affinity value of each schedule is calculated from the affinity function. The affinity function is defined as:

$$\text{Affinity}(p) = 1/\text{makespan} \tag{8}$$

From this relation, lower makespan value gives higher affinity value. Further the cloning of antibodies is done directly proportional to their affinity function values. Therefore, there will be more clones of antibodies that have lower makespan values than those of with higher makespan values in the new generated clone population. Costa et al [18] implemented an immune-based approach to minimize the makespan on parallel processors. An affinity function is defined based on makespan values of the schedules [19].

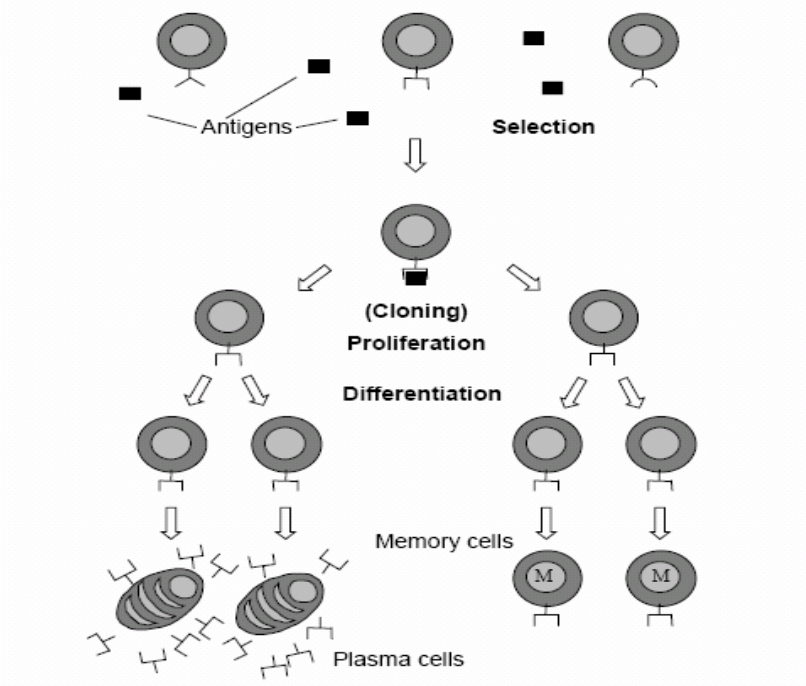

Figure 3: Clonal selection principle.

3.2 Affinity maturation principle

It consists of two methods namely Mutation and Receptor editing.
Mutation: A two phased mutation procedure were used for the generated clones [20].
a) Inverse Mutation b) Pair wise Interchange Mutation

Inverse mutation: For a sequence s, let i and j be randomly selected two positions in the sequences. A neighbour of s is obtained by inversing the sequence of jobs between i and j positions. If the makespan value of the mutated sequence is smaller than that of the original sequence then the mutated one is stored in the place of the original one. Otherwise, the sequence will be mutated again with random pair wise interchange mutation.

Pair wise interchange mutation: Given a sequence s, let i and j be randomly selected two positions in the sequence s. A neighbour of s is obtained by interchanging the jobs in positions i and j. If the makespan value of the mutated sequence is smaller than that of the original sequence, then store the mutated one in the place of the original one. In the case where the algorithm could not find a better sequence after the two-mutation procedure, then it stores the original sequence.

Receptor editing: After cloning and mutation processes, a percentage of the antibodies in the antibody population are eliminated and randomly created antibodies are replaced with them. This mechanism allows finding new schedules that correspond to new search regions in the total search space [21]. Figure 4 presents the flow chart for the proposed Artificial Immune System.

3.3 Flow Chart for the Proposed AIS Algorithm

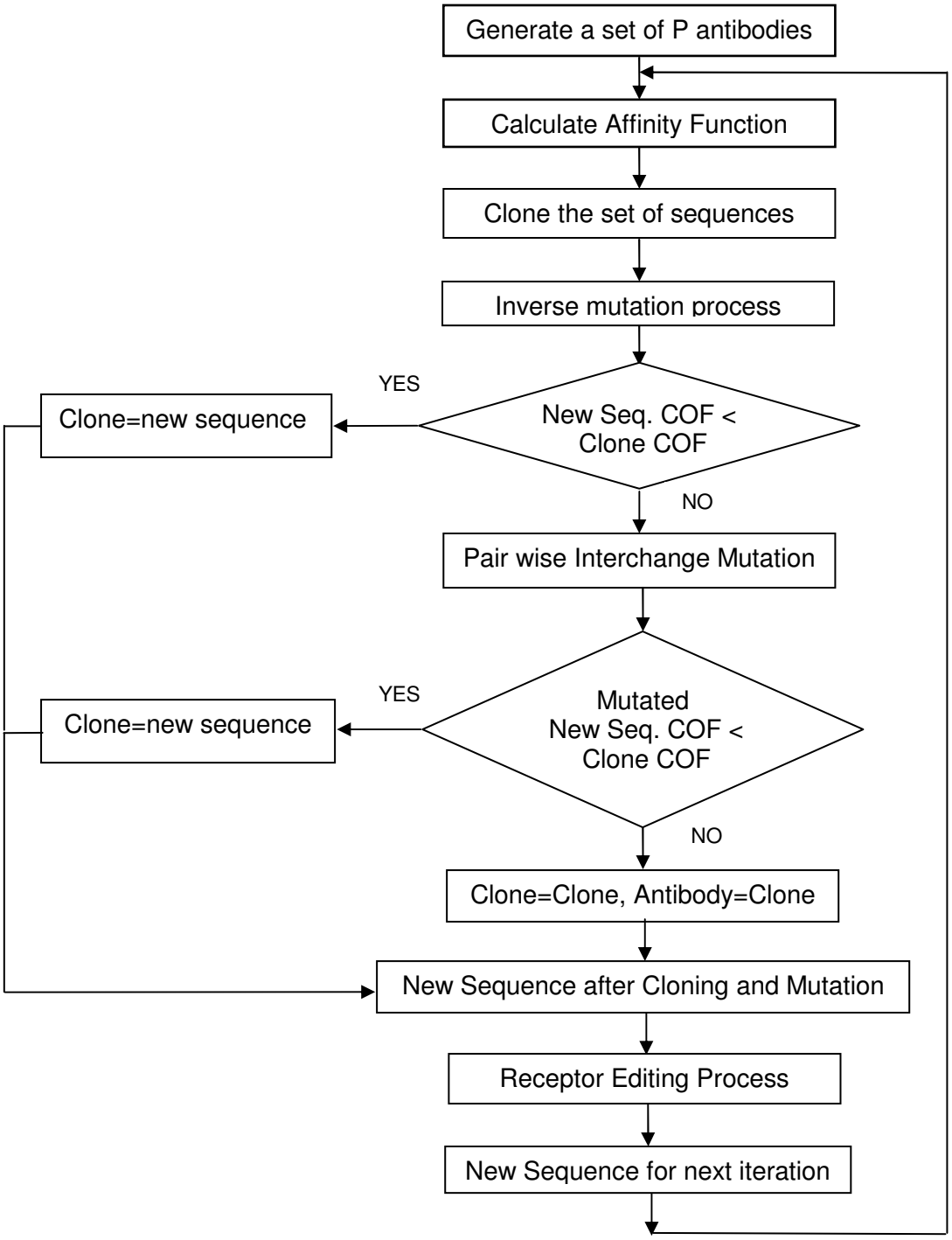

Figure 4: Flow chart for the proposed Artificial Immune System algorithm.

4. IMPLEMENTATION OF ARTIFICIAL IMMUNE SYSTEM (AIS) ALGORITHM

The artificial immune system algorithm is implemented for optimizing the sequences of parts into the machines, the AGVs sequence and the AS/RS sequence for the problem.

4.1 Generating Random Sequence

First initial populations of ten random sequences are generated and their respective Combined Objective Function (COF) values are calculated.
Example for random sequences from initial population # 1
15 28 43 18 41 21 30 20 12 16 17 1 4 42 26 35 8 36 10 7 27 38 31 6 34 32 25 9 5 2 29 3 40 33 23 37 13 19 11 14 24 39 22 **COF = 0.22839648**
40 42 3 35 7 31 37 21 1 12 13 16 28 33 10 14 19 24 5 26 15 6 43 41 18 32 34 30 11 17 8 36 39 22 4 9 27 20 25 2 23 38 29 **COF = 0.2314272**

4.2 Cloning the Sequences

An average of the COF is taken from the generated population and the affinity values are checked with the average, if the values of the affinities are greater than average values of COF of the population generated, then a clone is generated. A clone is nothing but a copy of the sequence. Here the sequences 1 and 2 were chosen because the COF values are lesser than the average values.

4.3 Mutation

A two phased mutation procedure is used for the generated clones. Two mutations namely Inverse Mutation and Pair-wise interchange mutations are carried out and the sequences corresponding to a lower COF than the original is chosen else the original sequence and its COF value is retained.

Example for Inverse mutation:

Inverse mutation i=4 j=42
Original Sequence
15 28 43 18 41 21 30 20 12 16 17 1 4 42 26 35 8 36 10 7 27 38 31 6 34 32 25 9 5 2 29 3 40 33 23 37 13 19 11 14 24 39 22 **COF = 0.22839648**
15 28 43 18 24 14 11 19 13 37 23 33 40 3 29 2 5 9 25 32 34 6 31 38 27 7 10 36 8 35 26 42 4 1 17 16 12 20 30 21 41 39 22 **COF = 0.2404571**
Example for Pair wise mutation:
Pair wise mutation i=4 j=26
Original Sequence
15 28 43 18 41 21 30 20 12 16 17 1 4 42 26 35 8 36 10 7 27 38 31 6 34 32 25 9 5 2 29 3 40 33 23 37 13 19 11 14 24 39 22 **COF = 0.22839648**
15 28 43 32 41 21 30 20 12 16 17 1 4 42 26 35 8 36 10 7 27 38 31 6 34 18 25 9 5 2 29 3 40 33 23 37 13 19 11 14 24 39 22 **COF = 0.23442212**

5. RESULTS AND DISCUSSION

The proper allocation of the subsystems in the FMS is important to achieve higher efficiency and productivity. Scheduling of FMS is not meant without considering the important subsystems such as AGVs and AS/RS. In this context, jobs, AGVs and AS/RS in the FMS have been scheduled simultaneously. The designed scheduling procedure with Artificial Immune System is developed in the JAVA language to conduct experiments. The results obtained through AIS are tabulated in Table IV. The graphs representing iterations Vs COF values for scheduling of parts, AGVs and AS/RS problem obtained by the implementation of AIS is presented in Figure 5. The graph is drawn choosing the weightage values as W1=0.4, W2 = 0.3 and W3 = 0.3.

Table IV: Comparison of Results for Scheduling of Parts with AGVs and AS/RS.

Method	Parts Sequence	AGVs Sequence	AS/RS Sequence	COF
AIS	26 25 10 18 31 28 23 16 22 1 30 9 34 20 38 13 2 37 40 5 41 36 24 17 3 19 7 35 11 43 4 27 39 21 42 15 12 14 33 32 8 29 6	2 1 2 2 1 2 1 2 2 1 2 1 2 2 2 1 2 1 2 1 1 2 1 1 1 1 1 1 1 2 1 1 2 2 1 2 2 1 2	43 48 31 45 26 14 28 32 2 21 25 29 16 33 1 34 6 42 7 47 23 5 40 13 41 8 11 22 36 18 35 10 17 44 49 46 38 15 27 9 39 37 19	0.3063

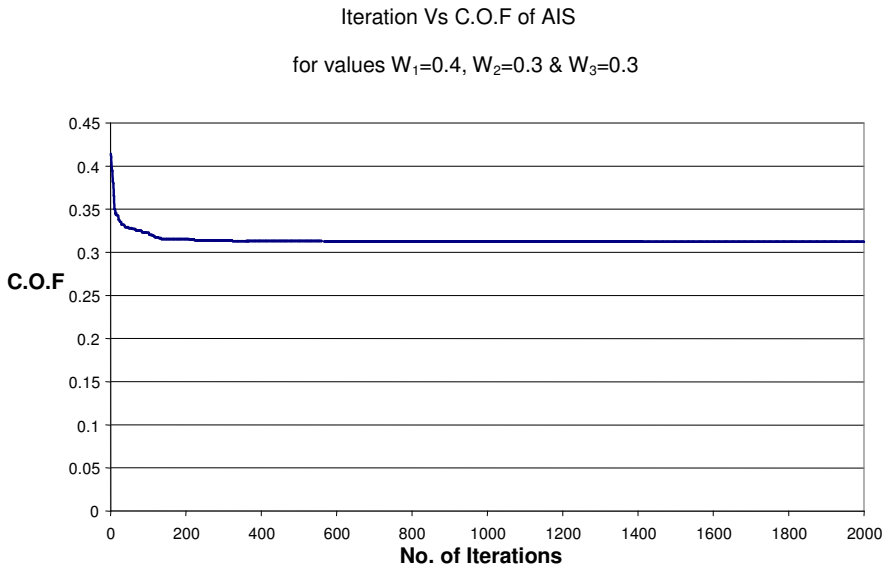

Figure 5: Iterations Vs COF Values Using Artificial Immune System.

6. CONCLUSION

To attain higher flexibility and productivity in the FMS, the subsystems in the FMS such as AGVs and AS/RS should be considered for the scheduling. In this context, this problem considers AGVs scheduling and AS/RS scheduling linked with jobs scheduling. This type of problem has been rarely dealt by researchers and is considered in this work. For the simultaneous scheduling of parts, AGVs and AS/ RS in this FMS, the schedules for jobs, AGVs and AS/RS storage assignments are obtained simultaneously for the minimum COF value by the devised procedure using AIS. Hence this type of approach can be used for various objectives and various FMS configurations also. The AIS parameters can be varied and the weightages given to the objectives can also be varied in future work.

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