

P-ACO Approach to Assignment Problem in FMSs

I. Mahdavi, A. Jazayeri, M. Jahromi, R. Jafari, and H. Iranmanesh

Abstract—One of the most important problems in production planning of flexible manufacturing system (FMS) is machine tool selection and operation allocation problem that directly influences the production costs and times. In this paper minimizing machining cost, set-up cost and material handling cost as a multi-objective problem in flexible manufacturing systems environment are considered. We present a 0-1 integer linear programming model for the multi-objective machine tool selection and operation allocation problem and due to the large scale nature of the problem, solving the problem to obtain optimal solution in a reasonable time is infeasible, Pareto-ant colony optimization (P-ACO) approach for solving the multi-objective problem in reasonable time is developed. Experimental results indicate effectiveness of the proposed algorithm for solving the problem.

Keywords—Flexible manufacturing system; Production planning; Machine tool selection; Operation allocation; Multi-objective optimization; Metaheuristic.

I. INTRODUCTION

FLEXIBLE manufacturing system consist of some multi functional machines that are link together through material-handling system and the whole of the system control by a central computer. A FMSs have advantage of two well known production systems, flow line for mass production and job shop for mid variety production, that due to this advantage more attention to these systems is reasonable. Flexibility of these systems proposes different machine tool combinations for performing each operation that results several routes for each part type between machines. Each routes has specific completion time and production cost.

We should finding a set of appropriate routes for parts that lead to effective production cost with considering limitation of resources. Also finding appropriate routes for each part or assignment of operations to appropriate machine tool combination is one of the difficult tasks in these environments

I. Mahdavi, Assistant Professor, is with Department of Industrial Engineering, Mazandaran University of Science and Technology, Babol, Iran (+9891-11131380, e-mail:irajarash@rediffmail.com).

A. Jazayeri, Graduate Student, is with Department of Industrial Engineering, Mazandaran University of Science and Technology, Babol, Iran (phone: +9891-25440956; fax+9821-55387926, e-mail:seyed_ali_jazayeri@yahoo.com).

M. Jahromi, Graduate Student, is with Department of Industrial Management, Islamic Azad University, Khomein Branch, Iran (phone: +9893-54015954, e-mail: mhm_jahromi@yahoo.com)

R. Jafari, Graduate Student, is with Department of Industrial Management, Islamic Azad University, Khomein Branch, Iran (phone: +9891-23092075)

H. Iranmanesh, Assistant Professor, is with "University of Tehran" & "Institute for Trade Studies & Research", Tehran, Iran (corresponding author, phone: +9821-88021067, fax: +9821- 88013102, e-mail: hiranmanesh@ut.ac.ir).

and directly effect production costs and times. Researchers have developed different approaches for this problem. [4] developed a 0-1 mixed integer programming model to machine tool selection and operation allocation and presented an ant colony optimization approach to operation assignment in FMS with assuming that each machine has specific available time and tools can not transfer between machines during the production phases [4]. [5] presented a heuristic approach for tool selection in FMS based on the life over size ratio of each tool that used part AGVs and tool AGVs. [7] developed an integrated model that performs operation sequence and tool selection simultaneously into the direction that minimizes tool waiting time when the tool is absent, decision point of tool selection is not after finishing an operation by a tool but after machining a part in their paper. [8] presented an approach to production planning of FMS that having four objective: minimizing total flow time, machine workload unbalance, greatest machine workload and total cost using an efficient multi-objective genetic algorithm that make use of Pareto dominance relationship to solve the problem [8]. [9] represented a modeling for loading problem in FMS as 0-1 mixed integer programming problem and with the output of the model generated a detailed operation schedule [9]. [10] extended modeling of loading problem of FMSs and using a hybrid tabu search and simulated annealing-based heuristic approach to solve the problem of minimization of system unbalance and maximization of throughput are considered. [11] presented a heuristic based on multi stage programming approach to solve problem of minimization of unbalance while satisfying the technological constrains such as availability of machining time and tool slots.

Because of the large-scale nature of many problems and solving of them in reasonable time is infeasible. Researchers have developed effective metaheuristics. Each metaheuristic algorithms use a specific mechanism to escape from local optima. [1] initially proposed ant colony optimization (ACO) that is inspired by the behavior of real ants, ACO is a parallel search over several constructive computational threads based on local problem data and on a dynamic memory structure containing information on quality of previously obtained results. ACO is a construction procedure, a constructive heuristic start from a null solution and add elements to build a good complete solution, and probabilistically build solutions. ACO Iteratively adding solution components to partial solution till represents many solutions. In ACO ants work concurrently and independently. [2] first developed *pareto ant colony optimization* for multi- objective combinatorial optimization and applied *P-ACO* approach to solve the multi-objective portfolio selection problem that this approach

considers the classical ant colony systems as the underlying ant colony optimization but global pheromone update is different. They have shown that *P-ACO* perform particularly well for this class of problem. They have supplemented *P-ACO* by an integer linear programming preprocessing procedure that identify several efficient portfolio solutions within a few seconds and correspondingly initialize the pheromone trail before running *P-ACO*.

Many researcher proposed ACO algorithms for solving multi-objective problems [6], [12], [3],[13].

II. PROBLEM DESCRIPTION

As mention above an FMS consist of many CNC machines and production costs dependent to what allocation of tools to the machines and assignment of operations to these machine tool combinations are made. The tool allocation is to assign required tool to the tool magazines of the machines. Because in industry there are many objectives so that all of them are important and usually these objectives are in contrast so multi-objectives application in industry is more and near to real situations. Some of the more appropriate objectives in FMS production systems are minimizing the machining costs, set-up costs and material handling costs. Due to the complexity of the tool selection and operation allocation problem, most models have constructed so far ignore tool life and size or simply assume a constant tool life and constant tool size for all the tools and some of these consider tool life and size in the mathematical model [5], but they ignore those for their metaheuristic approach. In the *pareto ant colony optimization* approach is developed for the problem, we consider variable tool life and tool size for each tool. On the other hand machines are generally equipped with tool magazines where they can hold several tool types to perform various operations on the part therefore in this paper variable tool magazine for each machine is considered. In the proposed model and the metheuristic we consider following assumptions:

- The processing time of operation in a batch is assumed to be identical.
- Operations to be performed by the machine tool combination are preemptive.
- Each tool assigned to one machine at the beginning of the production period until the end of the production period.
- A tool can not be duplicated in the same tool magazine.
- Tool magazine of each machine may have different number of tool slots of identical shape and size.
- Tool magazine of each machine may have different number of tool slots of identical shape and size.
- Each tool occupies equal number of slots on different machine.
- Each tool has specific tool life.
- Available time of machines is limited.
- Parts are transferred between machines with part AGVs.

- Parts are brought out from input buffer for machining of their operations.
- There is enough buffer in the each machine and after performing the last operation that part is stay on the machine.

III. MATHEMATICAL FORMULATION

In this section a multi-objective mathematical model for machine tool selection and operation allocation problem is presented.

A. Notations

The following notations for formulating the multi-objective assignment problem in FMS are introduced:

p	Part index; $1 \leq p \leq P$ that P is the total number of parts must be produced.
m, q, c ,	Machine and part storage indexes ; $0 \leq m, q, c \leq M$ that M is the number of available machines and 0 indicate part storage.
l	Tool index; $1 \leq l \leq L$ that L is the number of tools.
O	operation index; $1 \leq o \leq O_p$ that O_p is the number of operation for part type p .
MH_{qm}	Material-handling cost for a part from machine q to machine m .
C_{poml}	machining cost for operation o of part type p on machine m using tool l .
T_{poml}	Machining time for operation o of part type p on machine m using tool l .
SU_m	Set-up cost for machine m .
AT_m	Available time on machine m .
TL_l	Tool life of tool l .
B_p	Batch size for part type p .
A	Part's stage index: $1 \leq a \leq A$ each part's operation is produced in one part's stage that for each part A equals to O_p .
TS_l	number of slot tool l occupy on tool magazine.
MC_m	volume of tool magazine capacity for machine m

B. Decision Variables

x_m	Zero-one variable, equal one if machine m is selected for performing operation(s) with tool(s) as machine tool combination(s); equal zero Otherwise.
v_{ml}	Zero-one variable, equal one if tool l and machine m made machine tool combination to perform operation(s); equal zero Otherwise.
r_{apqml}	Zero-one variable, equal one if operation o of part p is performed using machine m and tool l , as $m-l$ machine tool combination, in stage a of the part

that this part came from machine or part storage q in the stage $a-1$ of the part ; equal zero Otherwise.

C. Multi-Objective Mathematical Model

It is appropriate to minimize some production cost like machining cost, set-up cost and material-handling cost so there are three objectives to be minimized in the multi-objective machine tool selection and operation allocation problem. Similar problem has been attempted by [4] as 0-1 mixed integer programming. Here the mention problem as 0-1 integer programming is presented as follows:

D. Objectives

1-Minimization of machining cost with considering batch of each part:

$$F_1 = \sum_{p=1}^P B_p \sum_{a=1}^A \sum_{o=1}^{O_p} \sum_{q=0}^M \sum_{m=1}^M \sum_{l=1}^L c_{poml} r_{apoqml} \quad (1)$$

2- Minimization of set-up cost:

$$F_2 = \sum_{m=1}^M SU_m x_m \quad (2)$$

3- Minimization of material-handling cost with considering batch of each part:

$$F_3 = \sum_{p=1}^P B_p \sum_{a=1}^A \sum_{o=1}^{O_p} \sum_{q=1}^Q \sum_{m=1}^M \sum_{l=1}^L MH_{qm} r_{apoqml} \quad (3)$$

E. Constraints

1- The total machining time of operations is assigned to machine should not exceed more than available time on the machine.

$$\sum_{p=1}^P B_p \sum_{a=1}^A \sum_{o=1}^{O_p} \sum_{q=0}^M \sum_{l=1}^L T_{poml} r_{apoqml} \leq At_m \quad \forall m \quad (4)$$

2- Tools have specific lifetime that total time of performing these operations should not exceed of their lifetime.

$$\sum_{p=1}^P B_p \sum_{a=1}^A \sum_{o=1}^{O_p} \sum_{q=0}^M \sum_{m=1}^M T_{poml} r_{apoqml} \leq Tl_l \quad \forall l \quad (5)$$

3- Each operation must be performs with a machine tool combination in one stage of the part. Also this part can come from part storage or another machine or the same machine that priori operation has performed:

$$\sum_{a=1}^A \sum_{q=0}^M \sum_{m=1}^M \sum_{l=1}^L r_{apoqml} = 1 \quad \forall p, o \quad (6)$$

4- This constraint states for performing operation with a machine-tool combination, first the machine must be set-up:

$$\sum_{a=1}^A \sum_{q=0}^M \sum_{l=1}^L r_{apoqml} \leq x_m \quad \forall o, p, m \quad (7)$$

5- If a machine is selected at least one operation must be performed with the machine tool combination is been made from the machine with a tool, we show this state with this constraint:

$$\sum_{a=1}^A \sum_{p=1}^P \sum_{o=1}^{O_p} \sum_{q=0}^M \sum_{l=1}^L r_{apoqml} \geq x_m \quad \forall m \quad (8)$$

6- This constraint states in each stage of each part just one operation can be performed.

$$\sum_{o=1}^{O_p} \sum_{q=0}^M \sum_{m=1}^M \sum_{l=1}^L r_{apoqml} = 1 \quad \forall p, a \quad (9)$$

7- This constraint guarantee each operation must be performed in one stage with respect to precedence relationship between operations:

$$\sum_{p=1}^P \sum_{q=0}^M \sum_{m=1}^M \sum_{l=1}^L r_{apoqml} = 0 \quad \forall o, a \neq o \quad (10)$$

8- This constraint states that each tool just can be assigned to one machine:

$$\sum_{m=1}^M v_{m,l} \leq 1 \quad \forall l \quad (11)$$

9- If one machine tool combination be constructed then at least one operation must be performed by this combination:

$$\sum_{a=1}^A \sum_{p=1}^P \sum_{o=1}^{O_p} \sum_{q=0}^M r_{apoqml} \geq v_{ml} \quad \forall m, l \quad (12)$$

10-This constraint shows the relation ship between to decision variables:

$$\sum_{a=1}^A \sum_{q=0}^M r_{apoqml} \leq v_{ml} \quad \forall p, o, m, l \quad (13)$$

11- This constraint keeps continuity movement of part between machines and state if one operation be performed on one machine then previous operation of this part has been performed on the same machine or another machine.

$$\sum_{a=1}^A \sum_{m=1}^M \sum_{l=1}^L r_{apoqml} \leq \sum_{a=1}^A \sum_{c=1}^M \sum_{l=1}^L r_{apo-1cq-l} \quad \forall p, o \geq 2, q > 1 \quad (14)$$

12- For machining first operation of each part that part must be brought from part storage by AGV on a machine:

$$\sum_{m=1}^M \sum_{l=1}^L r_{1p11ml} = 1 \quad \forall p \quad (15)$$

13- This constraint states each part once is brought by part AGV from part storage:

$$\sum_{a=1}^A \sum_{o=1}^{O_p} \sum_{m=1}^M \sum_{l=1}^L r_{apoml} = 1 \quad \forall p \quad (16)$$

14-This constraint states limitation of assigning tools on machine with considering tool magazine capacity of each machine:

$$\sum_{l=1}^L TS_l v_{ml} \leq MC_m \quad \forall m \quad (17)$$

IV. PARETO ANT COLONY OPTIMIZATION (P-ACO) APPROACH FOR THE MULTI-OBJECTIVE OPTIMIZATION PROBLEMS

As mention above because solving the problem with considering real production situation in reasonable time is infeasible in this section a methuristic approach for solving the problem is presented. For extracting the best solution we use the concept of *pareto dominance relationship* for selecting the final solutions.

A. Pareto Dominance Relationship

Multi-objective optimization are characterized by the fact that several objective must be optimized simultaneously and because usually these objectives are in contrast with another hence there is not a solution that optimized all the objective together like single objective optimization. In multi-objective optimization we are going to find a set of solutions that these solutions are not definitely prefer rather than each other and all of them are acceptable these solution called non-dominated solutions. A multi-objective combinatorial optimization problem can be defined as follows.

Assume our multi-objective combinatorial optimization have k objective, all of them must be minimized:

$$\text{Minimise } F(X) = \{F_1(X), \dots, F_k(X)\} \quad (18)$$

In *pareto optimality* X is called Pareto optimal solution if there is not any X' that:

$$\forall k: F_k(X') \leq F_k(X) \text{ and } \exists l: F_l(X) \leq F_l(X') \quad (19)$$

in this case X is called *non-dominated solution*.

$$\text{If } \forall k: F_k(X) \leq F_k(X') \quad (20)$$

then X is called *weakly dominate* X' .

Pareto optimal front define a vector X so there are not any vector that dominate the vector X .

In Fig. 1, a and b are non-dominated solutions in the solution space and c and d are dominated solutions by both a and b solutions.

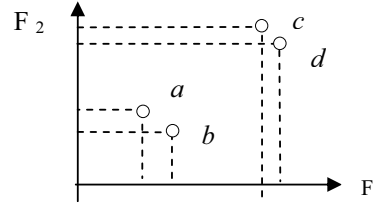


Fig. 1 Dominated and non-dominated solutions in bi-criteria space

B. Pareto Ant Colony Optimization (P-CO)

Pareto ant colony optimization (P-ACO), proposed by [2] for solving the multi-objective portfolio selection problem. It consider the classical ACS as the underlying ACO algorithm but the global pheromone update is performed by using two different ants, the best and the second-best solutions generated in the current iteration for each objective k .

In P-ACO for each objective k one pheromone matrix τ^k is considered. At every algorithm iteration, each ant uses a random vector $p = (p_1, \dots, p_k)$ generate with uniform distribution to combine the pheromone trail and heuristic information. When an ant has to select the nest node to be visited, it uses the ACO transition rule considering the k pheromone matrices:

$$j = \begin{cases} \arg \max_{j \in \Omega} \left(\left[\sum_{k=1}^K p_k \cdot \tau_{ij}^k \right]^\alpha \cdot \eta_{ij}^\beta \right), & \text{if } q \leq q_0 \\ j' & \text{otherwise.} \end{cases} \quad (21)$$

where η_{ij} is an aggregated value of attractiveness of edge (i, j) where often called visibility or heuristic information, q is a random number between 0 and 1, Ω indicate the feasible set of nodes that ant can select for transferring, τ_{ij}^k is the pheromone amount between position nodes i, j that is sorted in pheromone matrices τ^k for objective k , K is the number of objectives, and j' is a node selected according to the probability distribution given by:

$$p(j) = \begin{cases} \frac{\left[\sum_{k=1}^K p_k \cdot \tau_{ij}^k \right]^\alpha \cdot \eta_{ij}^\beta}{\sum_{u \in \Omega} \left[\sum_{k=1}^K p_k \cdot \tau_{ij}^k \right]^\alpha \cdot \eta_{ij}^\beta}, & \text{if } j \in \Omega \\ 0 & \text{otherwise} \end{cases} \quad (22)$$

When an ant travels an edge a_{ij} , the ant performs the local pheromone update in each pheromone trail matrix. i.e. for each objective k , as follows:

$$\tau_{ij}^k = (1-\rho) \cdot \tau_{ij}^k + \rho \cdot \tau_0 \quad (23)$$

That ρ is pheromone evaporation rate and τ_0 is initial pheromone value. Where ρ is the pheromone evaporation rate and τ_0 is the initial pheromone value. Each time ant constructs its solution, at the end of iterations, global pheromone trail information according to following rule is updated:

$$\tau_{ij}^k = (1-\rho) \cdot \tau_{ij}^k + \rho \cdot \Delta \tau_{ij}^k \quad (24)$$

that they have assigned following value to $\Delta \tau_{ij}^k$:

$$\Delta\tau_{ij}^k = \begin{cases} 15 & \text{if } edge_{ij} \in \\ & \text{best\&end\&best\&solution} \\ 10 & \text{if } edge_{ij} \in \text{best\&solution} \\ 5 & \text{if } edge_{ij} \in \text{second\&best\&solution} \\ 0 & \text{otherwise} \end{cases} \quad (25)$$

C. Encoding

For encoding the problem of machine tool selection and operation allocation according to the algorithm, total number of pheromone matrices equals to objectives that must be optimized each for one objective. A directed graph is constructed for a given set of part type, machine tool combination and corresponding operations. Each node indicates a machine tool combination that performs one operation of one part. For each operation according to the production information may have more than one node that capable to perform operation.

At the beginning of the production each ant can perform many operations with considering precedent relationship between operations of each part. Whenever an ant chooses a node that indicates performing one operation with the specific machine tool combination all the other nodes related with the operation but on the other machine tool combinations must be removed from the feasible set of nodes that can be visited by the ant in the following steps of traveling. Also each time an ant chooses one machine tool combination for an operation the entire nodes that assigned the tool to the other machines must be removed from the feasible set of nodes that can be visited by the ant in its route.

After each ant performs a perfect set of nodes that indicates performing all the operations must be produced a solution has been constructed means a route is visited by the ant. If the solution ignores each of constraints such as tool life, tool size, machine available and magazine capacity this is infeasible solution and is removed from other calculations.

D. Decision Rule and Local Pheromone Update Rule

According to the P-ACO approach as we say each ant randomly select first node from feasible set of nodes at the beginning of the travel. After that many nodes is not feasible for this ant also the node that selected by this ant. In fact after choosing each node the feasible set of node that can be visited by the ant must be updated. After that the ant selects next node j from feasible set of nodes according to Eq.(21) where K is the number of objectives, equal to three in this problem. $q_0 \in [0,1]$ is a parameter that establish a compromise between intensification and diversification of the search space. α and β are the parameters which determine the relative influence of pheromone trail and heuristic information. Node j' is to be visited according to the Eq.(22). The local update is performed for each objective to prevent convergence and simulate the natural pheromone of evaporation of the pheromone according to Eq.(23).

E. Heuristic Information

We consider η_{ij} as an aggregated value, according to the algorithm. Our heuristic acts as greedy search and try to find node that lead to minimize the summation of machining cost and material handling cost in the traveling of the ant. The proposed formula considers the partial contribution of each move to the objective function value.

Assuming an ant want to travel from node i to node j , node i indicate performing operation o of part p with $m-l$ machine tool combination (p,o,m,l) and node j indicate operation o' of part p' with $m'-l'$ machine tool combination (p',o',m',l') also according to the assumption of production $m \neq m'$ and $o \neq o'$ else this transfer is infeasible, machining cost of node j is $C_{p'o'm'l'}$ and material handling cost between machines of two node is $MH_{mm'}$, based on this assumption the following formula is proposed to calculate the desirability of move from node i to node j :

$$\eta_{ij} = \frac{1}{\frac{1}{C_{p'o'm'l'} + MH_{mm'}} + \sum_{j \in \Omega} \frac{1}{C_{p'o'm'l'} + MH_{mm'}}} \quad (26)$$

This constant value is calculates for each two feasible node as heuristic information.

F. Global Pheromone Update and Termination Condition

After each ant constructs a tour global pheromone update must be performed according to Eq. (24) and Eq. (25). For each objective best and second best solutions among all the solutions at this iteration must be considered and in the each pheromone trail matrix of each objective, the trail of the edges are identical to the edges of these solutions must be update.

After convergence condition is satisfied we select best solutions according to the Pareto sense. At the end of iterations, we keep non-dominated solutions that find so far and after maximum number times if algorithm can not find a solution that dominate previous non-dominated solutions the P-ACO algorithm is stopped.

In fact algorithm run till stagnation situation is encountered. Stagnation is situation in which all the ant travel the same tour and the solutions can not be improved.

G. Numerical Example and Computational Results

The proposed **P-ACO** algorithm has been coded in Microsoft Visual SQL Server and executed on Pentium III processor running at 900 MHz and 512 MB of RAM.

To illustrate the application of the proposed approach, we solve the problem of machine tool selection and operation allocation by considering tool life and tool size of each tool and magazine capacity of each machine. In the problem we assume there are three multi functional machines and six tools. Details of the multifunctional machines and tools are shown in Table I and II, respectively. Material handling cost between machines is given in Table III.

Table IV shows detail of machining costs and times of the orders with different alternative machine tool combinations. In this problem there are three part types with batch size 20, 20 and 15, respectively. We assume there are precedence relationships between operations as mention above.

TABLE I
DETAILS OF THE MACHINES

machine	set-up cost	available machining time	Magazine capacity
1	250	480	4
2	230	480	4
3	270	480	6

TABLE II
DETAILS OF THE TOOLS

tool	available time	Tool size
1	800	1
2	1000	2
3	1200	1
4	900	1
5	1000	1
6	700	2

TABLE III
MATERIAL-HANDLING COST BETWEEN THE MACHINES

	1	2	3
Input buffer	0	0	0
1	1	2	3
2		1	2
3			1

The proposed P-ACO contains seven parameters number of ants A , Max_Iter , α , β , ρ , q_0 and τ_0 . Also in this approach $\Delta\tau^k$ is a parameter but we fixed it and work on the other parameters.

These parameters effect the performance of the propose P-ACO. Extensive experimental tests were constructed to see the effect of different values on the performance of the proposed P-ACO algorithm.

The algorithms was tested on random problems with the same size and base on these observations, the following experimentally results are proposed to set the value of more effective parameters on the algorithm:

$$A = 2 \times (\text{number of feasible nodes at the beginig of itration}),$$

$$\alpha = 10, \quad b = 5, \quad \rho = 0.9, \quad \tau_0 = 1$$

In this problem according to the production information there are 69 nodes and ants had to construct their solution by these nodes. The number of ant was kept twice of the number feasible nodes that ant can select at the beginning of the iterations in this problem for example that is equal to 18.

The algorithm can obtain a set of non- dominated solution in a single run. In Table V three non-dominated solutions of solving the above problem with P-ACO approach are presented. For example in the first solution machine tool combination $m1-11$ (no. machine one and no. tool 1), $m1-12$ and $m1-16$ are selected for first, second and third operations of the first order/part, and $m2-13$, $m2-15$ and $m2-15$ are selected for first, second and third operations of the second order and $m1-11$, $m1-16$ and $m1-14$ are selected for first, second and third operations of the third order by one of an ants.

Each of the solutions nearly has a minimum cost in one objective and decision makers with considering limitation of sources and importance of them choose the appropriate production plan.

Mathematical model is solved by Lingo 8.0 as a single objective model that minimizes summation of all the three objectives and non-zeros decision variables of the above problem are as follow:

$$r_{111031}=1, r_{212325}=1, r_{313226}=1, r_{121033}=1, r_{222325}=1, r_{323225}=1, r_{131031}=1, r_{323233}=1, r_{333334}=1.$$

The developed algorithm has found solution of the single objective mathematical model too the third solution is the solution that obtains from mathematical model. According to the definition of non-dominated solution none of the three non-dominated solutions has not minimum objective function in the three objectives, simultaneously. For example third solution, solution obtain from single objective mathematical model and P-ACO approach, has minimum objective function in machining cost objective function while first and second solution have minimum objective function in set-up cost and material-handling cost objective functions. Also in each solution different machine is used this additional freedom degree rather than single objective approach is appropriate for decision maker.

In the first and third solutions for producing all of the orders we need set-up two machines while in the second production plan we need just one machine. As we see in the multi-objective approaches there are multiple choices for decision maker and with considering limitation and worth of the resources decision maker can select appropriate option.

TABLE IV
DETAIL OF PRODUCTION COSTS AND TIMES WITH DIFFERENT ALTERNATIVE MACHINE TOOL COMBINATIONS

part type	batch size	operation	tool options	machining time on different machine			machining cost on different machine			
				1	2	3	1	2	3	
1	20	1	1	6	6	1	4	4	6	
			3	7	6	3	3	5	8	
			2	5	6	3	3	3	5	
		2	4	6	5	4	5	6	6	
			5	4	4	8	5	8	5	
			3	3	8	9	2	4	3	
		3	4	4	5	8	8	8	2	
			6	3	3	6	3	2	2	
			<hr/>							
2	20	1	1	5	6	8	7	7	3	
			3	7	8	6	3	2	5	
			2	3	6	7	5	3	3	
		2	4	5	6	8	3	3	2	
			5	9	2	5	1	5	3	
			3	3	8	6	3	4	5	
		3	5	3	3	9	8	9	2	
			6	6	5	9	5	8	7	
			<hr/>							
3	15	1	1	5	6	5	5	3	6	
			3	8	4	7	5	6	8	
		2	3	5	6	2	2	3	5	
			6	4	6	8	8	8	3	
			3	2	9	9	3	3	8	
		3	4	9	9	5	2	3	5	
			5	6	9	5	4	3	9	
			<hr/>							

TABLE V
DETAILS OF THREE NON-DOMINATED SOLUTIONS OF THE P-ACO ALGORITHM

solutions	route has been constructed by ant		machining cost	set-up cost	material handling cost
	<i>p,o,m,l</i>	<i>p,o,m,l</i>			
1	1,1,1,1	3,1,1,1	810	480	110
	3,1,1,1	3,2,1,6			
	3,2,1,6	3,3,1,4			
	3,3,1,4	1,2,1,2			
	1,2,1,2	1,3,1,6			
	1,3,1,6	2,1,2,3			
	2,1,2,3	2,2,2,5			
	2,2,2,5	2,3,2,5			
2	1,1,1,3	3,1,1,1	1005	250	110
	3,1,1,1	3,2,1,3			
	3,2,1,3	3,3,1,4			
	3,3,1,4	1,2,1,5			
	1,2,1,5	1,3,1,3			

	1,3,1,3	2,1,1,3			
	2,1,1,3	2,2,1,5			
	2,2,1,5	2,3,1,3			
	2,1,3,3	2,2,2,5			
	2,2,2,5	2,3,3,3			
	2,3,3,3	1,1,3,1			
3	1,1,3,1	3,1,3,1	560	500	150
	3,1,3,1	3,2,3,3			
	3,2,3,3	3,3,3,4			
	3,3,3,4	1,2,3,3			
	1,2,3,3	1,3,3,1			

Fig. 2 reveals a set of non-dominated solutions is produced by P-ACO. This solution can be provided for decision makers in a single run of the algorithm. This set of solutions could provide a better exploitation of the resources of FMSs.

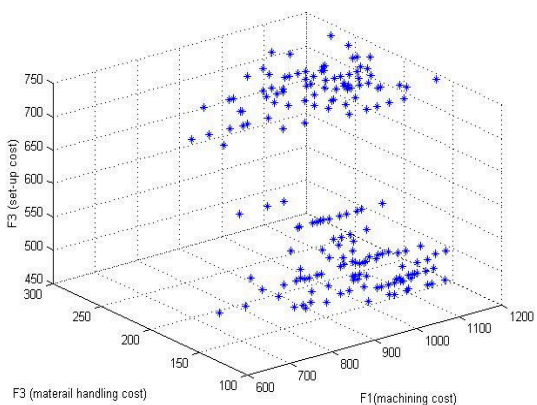


Fig. 2 The projection of dominated and non-dominated solutions from a run of the P-ACO approach

V. CONCLUSION

In this paper, the machine tool selection and operation assignment problem is considered. For this problem a mathematical model is developed. The multi-objective problem is solved by P-ACO approach. The attempted experiments show that the P-ACO approach is effective and efficient for the multi-objective problem.

We consider precedent relationship between operations and real constraint such as tool life, tool size, machine available, ant magazine capacity of each machine.

The complexity of the problem is determined by the number of machines, tools and orders. If the complexity increased, the computational time may be increased.

The proposed algorithm can produce a set of non-dominated solution for decision maker in a single run of the algorithm. The advantage of producing a set of non-dominated solution is that decision maker can compare different production plan with different cost and select one of them with considering limitation of resources while single objectives approaches can obtain one production plan for decision maker and can not review different production plans.

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