

Application of Ant algorithm in virtual manufacturing cells

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Abstract:

In this work, Ant algorithm is applied for scheduling tasks in virtual manufacturing cells (VMC). In virtual manufacturing cells, machines are randomly arranged in the workshop area. The task to be processed selects appropriate machines based on pre-determined objectives. The selection of the machinery turns into a complicated problem if there are several tasks for processing. There are a limited number of machines of any type in this workshop and the objectives are the minimization of the range of operation (sequence of tasks and starting time for each task) and the sum of the distances travelled by the entire piece. A number of standard problems were solved using the Ant algorithm in order to evaluate the efficiency of the algorithm. The results obtained show that the Ant algorithm offers good solutions in shorter times.

Keywords: Virtual Manufacturing Cells, Ant algorithm, Scheduling, Mixed integer programming.

1. Introduction

Many researchers have suggested new layouts for manufacturing cells (virtual, dynamic and holonic cells) to overcome the disadvantages of the conventional cellular manufacturing systems (CMS). One of the methods is the virtual manufacturing cells first developed by the Committee of National Standards. In a virtual manufacturing cell, the machines are assigned to a part or family of parts, as in a regular cell. However, the machinery is not physically located in a continuous area. This logical structure prevents the necessity of the expensive and time consuming re-layout of the workshop area and allows for quick response to the changing conditions.

In this work, the scheduling of tasks in virtual manufacturing cells is focused on. A situation is considered in which there are different types of multiple parts. All different types of parts have different process routes and various multiple machines are available to carry out these processes. Each type of machine has a one or more single machine. All single machines are presumed to be capable of performing identical processes such as process times. Machines are located in different locations in the workshop area. Scheduling decisions are as follows:

-Assigning machines to parts

- Starting time in each machine

Using these decision variables, the objective function is the minimization of the sum of manufacturing time intervals and the total distance travelled.

This problem can be divided into two different path planning and simpler scheduling problems and solved separately. One of the best path planning algorithms that was presented recently is SPP algorithm [1]. This algorithm generates the globally optimal path from a start point to a goal point and is pretty fast. By applying this algorithm considerable amount of time will be saved because this algorithm can come up with the optimal solution in less than a second for very sophisticated environments. The second part of the problem which is inside of each cell is no-wait two-stage flexible flow shop scheduling problem with rework time and for this part of the problem [2]. Although we can reach to the solution soon, the final solution won't be globally optimal and we need to integrate these two problems into one part and solve it as a single optimization problem. However, this mentioned method can't achieve global solution. So, for finding global solution a mixed integer programming (MIP) formulation has been developed

for the problem. This model can only be used to solve small to medium sized problems. According to the literature, meta-heuristic algorithms are able to solve large size of problems [3, 4]. Therefore, in this paper, the Ant colony algorithm is developed to provide good solutions in shorter times.

2. Literature review

The main difference between VMC and CMS is the mechanism of their response to the differences in demands. The machines with identical production processes are spread over the workshop area [5,6]. This makes possible the re-assignment of the cells when demands change. Drolet [7] and Mark et al. [8] have divided the entire available scheduling time to time intervals to enhance the understanding of virtual cell concept.

McLean et al. [9] first proposed VMC concept. The method developed was for controlling a type of production, which was designed to produce products of very large variety and small amounts. McLean et al. [9] reported that the classification in virtual cells (VC) is not physical, but virtual. Therefore, the process data are grouped in computer controllers. Nomden et al. [10] have classified VC and introduced different fields for it. Irani et al. [11] have investigated a VMC system to minimize the distance travelled by the commodity. Suresh and Meredith [12] have used a fuzzy linear programming model for creation of a workshop using the VMC approach, that is; the system was still a workshop production system, but scheduling was carried out for different cells. Kannan and Ghosh [13-14] have investigated many rules corresponding to batch production scheduling since then.

Vakharia et al. [15] have proposed an analytical model for comparison of VMC and workshop production flow system. According to their studies, the available sources such as the number of processes, machines, packages and startup time must be separately defined and calculated in each time period.

3. Problem definition and formulation

Figure 1 shows a general conceptual design for VMC. In this design, each type of machine may consist of over one machine. Similar machines of each kind have not been located in close proximity. Different products have to be displaced between the machinery, which is expensive and time-consuming.

Therefore, similar machines have not been located in close proximity. The minimization of product displacement between machines to reduce time and cost must be considered as one of the objectives. Another factor, which must be considered as an objective function, is the operation time range. Shorter operation time range signifies greater system efficiency.

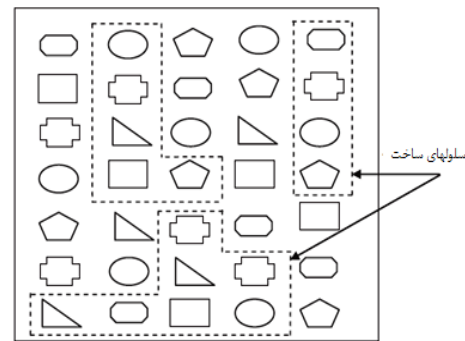


Figure 1. Schematic and conceptual design of VMC

The formulation of the problem is as follows: There are n tasks and m types of machines in the problem. There can more than one machine of any kind. $s(i)$ is a single machine belonging to the i th category. $s(i) \in i$. $s(i)$ type machines are located in different parts of the workshop and they cannot thus work in parallel. However, all machines of the i th group have identical speeds. $o_{j,h}$ is the h th function of the j th task. Each task has its own specific route and the machines on which $o_{j,h}$ can be processed have previously been determined. If $o_{j,h}$ is processed in i th machine, all single $s(i)$ machines are competing for selection.

Therefore, the problem consists of two parts: machine assignment and timing. Cycling is not allowed in this type of timing. All the tasks are available at time zero and must be performed non-stop up to the completion of processing. The distance between each couple of machine is clear.

Parameters

j : Task index ($j=1, \dots, n$)

i, k : Machine group index ($i, k=1, \dots, m$)

l : Index for arrangement in each machine ($l=1, \dots, l_{s(i)}$)

h : Operation index ($h=1, \dots, h_j$)

$o_{j,h}$: h^{th} function of task j

$s(i)$: Single machine belonging to machine group i

N_j : Group size of task j

$P_{j,h}$: Processing time of operation h of task j

$D_{s(i),s(k)}$: Transportation cost for each task from machine $s(i)$ to machine $s(k)$

M : A very large number

W_q : Weight of the q^{th} objective function

Decision parameters

C_{\max} : Completion time of the last task to leave the system

$Y_{s(i),j,h}$: 1 if $s(i)$ is selected for operation $o_{j,h}$, otherwise zero

$X_{s(i),j,h,l}$: 1 if $o_{j,h}$ is carried out in machine $s(i)$ in arrangement l

$t_{j,h}$: Starting time of operation $o_{j,h}$
 $Tm_{s(i),l}$: Starting time of machine $s(i)$ in arrangement l

$$\min W_1 C_{\max} + W_2 \sum_{j=1}^n \sum_{h=1}^{h_j} \sum_{s(i)} Y_{s(i),j,h} Y_{s(k),j,h+1} D_{s(i),s(k)} N_j \quad (0)$$

subject to

$$C_{\max} \geq t_{j,h} + P_{j,h} N_j \quad \text{for } j = 1, \dots, n \quad (1)$$

$$t_{j,h} + P_{j,h} N_j \leq t_{j,h+1} \quad \text{for } \begin{cases} j = 1, \dots, n \\ h = 1, \dots, h_j - 1 \end{cases} \quad (2)$$

$$Tm_{s(i),l} + X_{s(i),j,h,l} P_{j,h} N_j \leq Tm_{s(i),l+1} \quad \text{for } \begin{cases} i = 1, \dots, m \\ j = 1, \dots, n \\ h = 1, \dots, h_j \\ l = 1, \dots, l_{s(i)} - 1 \end{cases} \quad (3)$$

$$t_{j,h} + M(1 - X_{s(i),j,h,l}) \geq Tm_{s(i),l} \quad \text{for } \begin{cases} i = 1, \dots, m \\ j = 1, \dots, n \\ h = 1, \dots, h_j \\ l = 1, \dots, l_{s(i)} \end{cases} \quad (4)$$

$$Tm_{s(i),l} + M(1 - X_{s(i),j,h,l}) \geq t_{j,h} \quad \text{for } \begin{cases} i = 1, \dots, m \\ j = 1, \dots, n \\ h = 1, \dots, h_j \\ l = 1, \dots, l_{s(i)} \end{cases} \quad (5)$$

$$\sum_{j=1}^n \sum_{h=1}^{h_j} X_{s(i),j,h,l} \leq 1 \quad \text{for } \begin{cases} i = 1, \dots, m \\ l = 1, \dots, l_{s(i)} \end{cases} \quad (6)$$

$$\sum_i Y_{s(i),j,h} = 1 \quad \text{for } \begin{cases} j = 1, \dots, n \\ h = 1, \dots, h_j \end{cases} \quad (7)$$

$$\sum_l X_{s(i),j,h,l} = Y_{s(i),j,h} \quad \text{for } \begin{cases} j = 1, \dots, n \\ h = 1, \dots, h_j \\ i = 1, \dots, m \end{cases} \quad (8)$$

$$C_{\max} \geq 0, \quad t_{j,h} \geq 0, \quad Tm_{s(i),l} \geq 0$$

$$Y_{s(i),j,h}, X_{s(i),j,h,l} \in \{0,1\} \quad (9)$$

4. Ant algorithm

One of the most important fields of research in recent years has been the development of innovative methods based on the nature to obtain good results in combined optimization problems. One of the most significant nature based innovative methods is the optimization of ant colony. In the Ant algorithm, the travel from city i to city j is performed according to

probability p_{ij}^k .

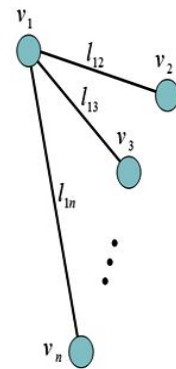
$$N_i = \{m \mid l_{im} \in L\} \quad (11)$$

$$N_i^k = \{m \mid m \in N_i \wedge m \notin \psi^k\} = N_i - \psi^k \quad (12)$$

p_{ij}^k is the

probability of selection of city i by k^{th} ant in city j , calculated using the following equation. The necessary primary equations are defined according to Figure 2.

$$p_{ij}^k = \begin{cases} \frac{(\tau_{ij})^\alpha (\eta_{ij})^\beta}{\sum_{m \in N_i^k} (\tau_{im})^\alpha (\eta_{im})^\beta} & \text{if } j \in N_i^k \\ 0 & \text{otherwise} \end{cases} \quad (10)$$



$$V = \{v_1, v_2, \dots, v_n\}$$

$$L = \{l_{ij} \mid (v_i, v_j) \in W \subseteq V \times V\}$$

$$G = (V, L)$$

$$J: L \rightarrow \mathbb{R}^{\geq 0}$$

$$J(l_{ij}) = d_{ij}$$

$$D = [d_{ij}]_{n \times n}, d_{ii} = 0$$

$$\eta_{ij} = \frac{1}{d_{ij}}$$

$$\Delta \tau_{ij}^k = \begin{cases} \frac{Q}{J(\psi^k)} & l_{ij} \in \psi^k \\ 0 & \text{otherwise} \end{cases} \quad (13)$$

Figure 2. Selection of the next city

α and β are two parameters, which control the weight ratio of pheromone effect and the values of the innovative method. They affect τ_{ij} and η_{ij} parameters in the probability of selection of city j by the ant in i .

Parameter τ_{ij} is proportional to the distance between i and j . Parameter τ_{ij} is proportional to the movement of the ants in the (i,j) path.

The following equations are used to update the concentration of the pheromone effect.

$\Delta \tau_{ij}^k$ is the increased surface of pheromone edge (i, j) by the k^{th} ant.

The pseudo-code Ant algorithm for the virtual manufacturing cells is as follows:

$$\tau_{ij} = \tau_{ij} + \sum_k \Delta \tau_{ij}^k \quad (14)$$

$$\tau_{ij} = (1 - \rho) \cdot \tau_{ij} \quad (15)$$

1. Initialize

Set $time:=0$ ($time$ is time counter)
 For each (i,j) set an initial $\tau_{ij} = c$ and $\Delta\tau_{ij} = 0$
 2.set $s:=0$ (s is a counter)
 For $k:=1$ to l do
 Select an operation from J'_k and place it in J_k and remove it from J'_k and J_k^c
 Select the machine that can do the selected operation
 3.repeat until $s \leq n$
 $s=s+1$
 for $k:=1$ to l do
 choose the next operation from J'_k and related machine according to the probability p_{ij}^k given by Eq(10)
 update J_k , J'_k and J_k^c
 4.for $k:=1$ to l do
 Compute the C_{max} for J_k and T_d (total traveled distance between machines)
 Compute $Z_k = \omega_1 \cdot C_{max} + \omega_2 \cdot T_d$
 Update $global\ order$ found
 For each (i,j) do
 For $k:=1$ to l do
 Update the pheromone according Eqs(13)&(15)
 $time:=time+1$
 5.if $time < TIME_MAX$ then
 Empty all J_k , J'_k and J_k^c
 Go to step 2
 Else
 Print $global\ order$ Stop
 In order to solve the problem using the Ant algorithm, some arrangements must be made. The tasks are divided into three separate sets. Set J is all the currently planned tasks. J_c indicates the tasks, which have not yet been planned. J' shows the tasks, which can be planned. These sets for the k th ant are represented by J_k , J_k^c and J'_k . Arc (i, j) is defined as transferring from location i to j . Each location shows one of the o_{ijs} .
 The objective function for each ant is defined as Z_k . Since Z_k is composed of two components; namely the distance travelled between the machines and the

completion time of the last task, coefficients ω_1 and ω_2 are defined in accordance with their degree of importance. The best response obtained using the algorithm is saved in the global order. This algorithm was encoded in Matlab and used to solve some standard problems. The results obtained are shown in Table 1.

5. Calculation results

The mathematical model of the problem and the Ant algorithm were encoded in GAMS/Cplex 22 and Matlab, respectively. Twenty nine standard problems were solved using these two programs.

ω_1 and ω_2 were considered as 0.95 and 0.05, respectively. The Ant algorithm was run five times for each problem and the average values are given in the following table. Considering the dimensions of the problems, the number of ants varied from 100 to 500. Here, the time limit to complete the running of the Ant colony algorithm was 200 seconds and whenever the best response was obtained from the algorithm, the time was entered in the table in the CPU column. C_{max} and TTD represent the completion time of the last task and the total distance travelled by the parts, respectively. FF shows the value of the objective function, which is the weight sum of the completion time of the last task and the total distance travelled.

Table 1. Comparison of the results obtained from MIP and ACO

#	n	x	m	$\sum s(i)$	MIP solution				ACO approach			
					C_M	TTD	FF	CPU(s)	C_M^*	TTD*	FF*	CPU(s)
1	4	x	3	6	434	2219	523	<1	434	2219	523	<1
2	4	x	3	8	320	2322	420	<1	320	2322	420	<1
3	4	x	4	10	544	4802	757	<1	544	4802	757	<1
4	5	x	2	4	524	3948	695	11	524	3948	695	<1
5	5	x	3	6	351	3793	523	8	351	3793	523	2
6	6	x	2	4	444	8220	836	55	447	8220	836	<1
7	6	x	3	6	561	3456	706	10	561	3456	706	2
8	6	x	3	8	360	3106	497	14	360	3106	497	2
9	6	x	3	10	390	3563	549	11	390	3563	549	2
10	7	x	2	4	594	5999	864	2258	594	5999	864	4
11	7	x	3	6	665	8795	1071	226	665	8795	1071	3
12	7	x	4	10	684	8193	1059	1	684	8193	1059	4
13	8	x	3	6	544	7792	906	379	544	7792	906	5
14	8	x	3	8	704	7570	1047	612	704	7570	1047	7
15	8	x	4	10	572	8465	967	10	572	8465	967	6
16	8	x	4	12	775	6948	1084	22	775	6948	1084	9
17	8	x	4	15	735	10173	1207	1670	735	10173	1207	12
18	9	x	3	6	620	11987	1188	-	620	11987	1188	10
19	9	x	4	10	924	9246	1340	-	924	9246	1340	11
20	9	x	4	12	667	10955	1181	-	667	11268	1197	10
21	10	x	3	8	800	7798	1150	-	800	7192	1119	13
22	10	x	3	10	925	8396	1299	3388	925	8396	1299	13
23	10	x	4	12	714	10983	1227	-	714	10983	1227	13
24	10	x	5	15	900	10640	1387	316	900	10640	1387	17
25	10	x	6	20	992	15035	1694	-	975	14810	1666	20
26	11	x	3	6	972	10044	1425	308	972	10044	1425	15
27	11	x	3	8	797	8929	1203	-	806	8169	1174	14
28	11	x	4	10	910	12575	1493	-	828	13163	1445	20
29	11	x	4	12	704	11424	1240	-	621	10965	1204	17

6. Conclusion

In this work, virtual manufacturing cells (VMCs) were studied and the Ant algorithm was used for solving this problem given the complexity of the problem. To evaluate the performance of the Ant algorithm, the results obtained using this algorithm to solve a number of standard problems were compared with those from MIP. The results showed the efficiency of the Ant algorithm from both aspects of the quality of the responses obtained and the time required for obtaining the responses.

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