A Study on Performance Evaluation of Different Parameter Settings of Particle Swarm Optimization in Job Shop Scheduling Problem

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ABSTRACT

This study is to present a particle swarm optimization (PSO) to solve a job shop scheduling problem with the objective of minimizing a makespan. The solution representation of a particle that is encoded with a permutation of all operations on jobs. The operations are ordered by precedence constraints. For the performance evaluation, each particle is evaluated by a quality of the fitness function. In the particle swarm optimization model, the effect of parameters, like the swarm size, on performance are investigated in this paper. In different swarm sizes, the performance of proposed methodology is tested on forty well-known benchmark problems from the OR-library. The computational results demonstrate that the proposed methodology can effectively solve a job shop scheduling problem and also take less processing time although run on a personal computer.

CCS Concepts

• Computing methodologies → Planning and scheduling.

Keywords

particle swarm optimization (PSO); job shop scheduling problem (JSSP); parameter setting; permutation encoding schema.

1. INTRODUCTION

In competitive markets, manufacturer produce their products to compete with specified due dates and production volumes. Therefore, efficient production scheduling has become a critical task of companies and a focusing problem for researchers. In a classification of scheduling problems, there are three basic multi-machine problems including an open shop scheduling problem (OSSP), a flow shop scheduling problem (FSSP), and a job shop scheduling problem (JSSP). The current work focuses on the JSSP, in which multiple jobs are processed on multiple machines. Each job must be processed on its own machine order for a predefined processing time. Therefore, a scheduling is to decide when to

process each job on different machines. The challenge here is to determine a feasible sequence of jobs on given machines with an objective of minimizing job completion times.

From past to present, a large number of techniques have been proposed for solving the JSSP, which can be classified into two categories: a mathematical approach and an approximation approach. Historically, the use of mathematic methods, such as integer programming [1] or branch and bound algorithm [2,3], for solving the JSSP were popular because they could achieve an optimal solution. However, the mathematics optimization methods have limitations on the large-scale problems due to polynomial-time solutions. Therefore, a mathematical approach is suitable for small combination problems. That is why many researchers have turned their attention to an approximation approach for solving larger complex problems. In recent years, various methods of an approximation approach have been proposed such as genetic algorithm (GA) [4,5], simulated annealing (SA) [6,7], particle swarm optimization (PSO) [6,7] and so on. It is evident that these powerful algorithms solve the JSSP as well. Although these approximation algorithms have no guarantee achieving optimal solutions, they can offer good solutions within a reasonable run-time.

There are ongoing efforts to improve a performance of the PSO for solving the JSSP, so many variations of the PSO have been proposed. Researchers are interested in studying what influence on finding an optimal solution. Like other approximation methods, a performance of the PSO depends on different factors such as parameter settings, local search method, problem representation, and problem size. In recent years, some studies introduced the PSO-based hybrid models for convergence improvement. For example, Bank et al. [7] compare the performance of the PSO with and without the proposed local search for solving the flow shop scheduling problem. The PSO with local search could have higher efficiency. Perez and Behdinan [8] presented the effect of the different setting parameters and functionality of a particle swarm optimization in classical structural optimization problem. This paper focuses on performance evaluation of different parameter settings of a particle swarm optimization in job shop scheduling problem.

The remainder of the paper is organized as follows: in section 2, the description of the JSSP is given. The standard particle swarm optimization is presented in section 3. Section 4 describes about a methodology and its computational results on test problems. Finally, the conclusions are presented in section 5.

2. BACKGROUND

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2.1 Job Shop Scheduling Problem

The job shop scheduling problems are defined as follows:

(1) A JSSP consists of a set of n jobs ($J = \{J_1, J_2, \dots, J_i, \dots, J_n\}$) and a set of m machines ($M = \{M_1, M_2, \dots, M_k, \dots, M_m\}$). Each job is not dependent on each other's job.

(2) Each job J_i consists of a predetermined sequence of operations ($J_i = \{O_{i1}, O_{i2}, \dots, O_{ij}, \dots, O_{ip}\}$); each of which has to move through a set of machines under three constraints. The first is no preemption constraint: when operation has already been started on a specified machine, there is no interruption before it is finished. The second is a resource constraint: each machine can handle only one operation of any job at a time. And the last is a precedence constraint: for maintaining precedence among operations of different jobs, each operation of any job is processed after all predecessor operations had finished.

(3) Each operation of any job is performed on specified machine for a given time.

Figure 1 shows the example of the job shop scheduling problem in 3x3 size (3 jobs x 3 machines = 9 operations). The first row of example J_1 has three operations. The first operation, $O_{11}(M_1, 2)$, must be operated on the machine M_1 in the 2 units of time. After it is finished, the second operation, $O_{12}(M_2, 3)$, can be operated on the machine M_2 in the 3 units of time. And the last operation is $O_{13}(M_3, 1)$ which is operated on the machine M_3 in the 1 unit of time. Like the first job, the others are operated on a specified machine within a given time.

	Operation 1	Operation 2	Operation 3
Job 1	$O_{11}(M_1, 2)$	$O_{12}(M_2, 3)$	$O_{13}(M_3, 1)$
Job 2	$O_{21}(M_2, 3)$	$O_{22}(M_1, 1)$	$O_{23}(M_3, 2)$
Job 3	$O_{31}(M_2, 2)$	$O_{32}(M_3, 3)$	$O_{33}(M_1, 2)$

$O_{ij}(M_k, T)$

O_{ij} an operation j of a job i

M_k a machine k

T a processing time of O_{ij} on a machine k

Figure 1. Example of a 3x3 JSSP.

From Figure 1, the example of 3x3 JSSP can be represented using a disjunctive graph as shown in Figure 2. The operations which belong to the same job are connected by conjunctive arcs. While the operations that must be performed in the same machine are connected by disjunctive arcs.

Figure 2. A disjunctive graph of 3x3 JSSP.

2.2 Particle Swarm Optimization

Particle swarm optimization was first introduced by Kennedy and Eberhart [10,11] in 1995. The PSO is a population-based optimization algorithm inspired by social behavior of bird flocking or fish schooling. Some birds or fish live as social groups in order to look for foods, migrate, and be protected from predators to survive. In foraging behavior, each individual communicates with others to share their own experience and use the experience of the swarm leader in order to find foods in the shortest possible time. These are used for guiding optimization search by simulating a swarm of particle fly to find foods in the solution space.

In the standard PSO, there is a swarm consisting of N particles where each particle i has a position vector, $\bar{X}_i$ and a velocity vector, $\bar{V}_i$ in D -dimensional size as equation (1) and (2), respectively.

$$\bar{X}_i(t) = \{x_1(t), x_2(t), \dots, x_D(t)\} \quad (1)$$

$$\bar{V}_i(t) = \{v_1(t), v_2(t), \dots, v_D(t)\} \quad (2)$$

In every iteration, the two best values, pBest and gBest, are updated by each particle. Individual particles keep their own personal best, pBest, which are associated with the best position that has archived so far. The global best, gBest, is the best position found among all particles in the swarm. Once pBest and gBest are updated, each particle must adjust its velocity vector according to equation (3), (4) and (5).

$$\bar{V}_i(t+1) = w \times \bar{V}_i(t) + p_i(t) + g_i(t) \quad (3)$$

$$p_i(t) = c_1 \times rand \times (pBest - \bar{X}_i(t)) \quad (4)$$

$$g_i(t) = c_2 \times rand \times (gBest - \bar{X}_i(t)) \quad (5)$$

where $\bar{V}_i(t+1)$ is a new velocity vector for next iteration, w is the inertia weight, the constant c_1 and c_2 are the cognitive parameter in itself and the social parameter in the swarm, and $rand$ is a random number.

$$\bar{X}_i(t+1) = \bar{X}_i(t) + \bar{V}_i(t+1) \quad (6)$$

After the new velocity vectors are calculated, each particle can move to its new position vector by using the equation (6). The searching needs to be repeated until some stopping criteria is met, for example, the maximum number of iteration, and the minimum error.

3. PROPOSED METHODOLOGY

There are three main steps for a study on performance evaluation of different parameter setting of particle swarm optimization for solving the JSSP, which are as follows:

3.1 Problem representation

For solving a job shop scheduling problem by the PSO algorithm, the first step is to choose a type of solution encoding. This study is to represent a position of each particle with a real encoding and then transform it into a permutation encoding. From an example of 3x3 JSSP in Figure 1, the position of the particle is formed as a problem solution by a vector shown in Figure 3(a). A particle vector is created with a length of 3x3 dimensions and with each dimension set to a value of random real values in the range of 0 to

1. After that a real-valued particle is transformed into a vector of integer from 1 to 9 according to its ordering. As shown in Figure 3(b), the integer vector is denoted by a job series. Finally, the position of particle formed as a job series is replaced by its 9 operations in given precedence of each job.

Figure 3. A representation of a particle for a 3x3 JSSP.

3.2 Fitness evaluation

Figure 4. A Gantt chart representation for a 3x3 solution.

The fitness function is used to evaluate the performance of each particle. For adapting the PSO to the JSSP, the fitness function is mapped to the objective function, that is to minimize the makespan value. Therefore, the solution represented by the position of the particle is used to calculate a makespan value by assignment operations on a given machine under problem constraints. From the example of permutation-based particle in Figure 3(d), That can be calculated the maximum of complete-time on all machines (called makespan) for 9 units of time as shown in Figure 4.

3.3 PSO solution for the JSSP

The process for implementing the PSO solution for the JSSP is described as follows:

Step 1: Initialize the parameter setting.

Step 2: Generate a swarm of particles, which is represented with a set of position vectors. A particle position is initialized with a random number in the range of [0, 2].

Step 3: Generate a particle velocity of each member of a swarm with a random number in the range of [-2, 2].

Step 4: Evaluate the performance of each member of a swarm by calculating a makespan through decoding its own position.

Step 5: Find the local best position (called pBest) by comparison the current fitness value with the previous value. If the current

fitness value is better than, then set it to the fitness value of pBest and also set the current position to the position of pBest.

Step 6: Find the global best particle (called gBest) by comparison the current fitness value with the best fitness value of swarm. Like the local best particle, if the current fitness value is better than, then set it to the fitness value of gBest and also set the current position to the position of gBest.

Step 7: Update the position and the velocity of each particle in a swarm.

Step 8: Repeat step 2-7 until a maximum number of iterations is reached.

From above mentioned, the PSO model is illustrated as a flowchart in Figure 5.

Figure 5. Flowchart of the PSO for the JSSP.

4. COMPUTATIONAL RESULTS

The methodology of particle swarm optimization was implemented in JAVA and ran on Intel® Core™2 Duo CPU E7500 2.93 GHz. with 4 GB RAM. The presented model was tested on 40 instances from the OR-library [9]. For the purpose of study on the parameter settings, the parameter values of PSO are set as follows: the constant C_1 and C_2 are set to 2, the inertia weight w is set to 1, the maximum number of generations is set to 1,000, and swarm size of initial population is set to 20, 40, 60, and 80. For each selected swarm size, each instance is randomly performed 10 times.

Table 1. Computational results of 40 difference instances

Instance	Size		20			40			60			80		
	m	n	BS	RE	CT	BS	RE	CT	BS	RE	CT	BS	RE	CT
la02	10	5	815	0.24	00:15	655	0.00	00:29	655	0.00	00:46	655	0.00	01:00
la03	10	5	755	0.26	00:15	597	0.00	00:30	597	0.00	00:46	597	0.00	01:01
la04	10	5	745	0.26	00:15	734	0.24	00:30	691	0.17	00:45	705	0.19	01:01
la05	10	5	593	0.00	00:15	613	0.03	00:29	616	0.04	00:45	612	0.03	01:00
la06	15	5	926	0.00	00:26	926	0.00	00:51	926	0.00	01:16	926	0.00	01:42
la07	15	5	1074	0.21	00:25	1098	0.23	00:51	1070	0.20	01:17	1050	0.18	01:42
la08	15	5	1087	0.26	00:26	1053	0.22	00:51	1042	0.21	01:17	1010	0.17	01:43
la09	15	5	1110	0.17	00:25	1061	0.12	00:49	1141	0.20	01:17	1100	0.16	01:42
la10	15	5	1044	0.09	00:25	1053	0.10	00:50	1020	0.06	01:16	1004	0.05	01:43
la11	20	5	1487	0.22	00:37	1390	0.14	01:16	1399	0.14	01:53	1382	0.13	02:32
la12	20	5	1228	0.18	00:39	1176	0.13	01:17	1172	0.13	01:54	1186	0.14	02:33
la13	20	5	1326	0.15	00:38	1370	0.19	01:16	1303	0.13	01:53	1297	0.13	02:34
la14	20	5	1373	0.06	00:38	1387	0.07	01:16	1397	0.08	01:53	1355	0.05	02:32
la15	20	5	1580	0.31	00:38	1470	0.22	01:16	1549	0.28	01:56	1486	0.23	02:32
la16	10	10	1232	0.30	00:33	1220	0.29	01:06	1250	0.32	01:39	1158	0.23	02:12
la17	10	10	1011	0.29	00:33	1068	0.36	01:07	1005	0.28	01:39	1075	0.37	02:14
la18	10	10	1191	0.40	00:33	1159	0.37	01:06	1088	0.28	01:39	1125	0.33	02:12
la19	10	10	1184	0.41	00:33	1210	0.44	01:06	1162	0.38	01:38	1116	0.33	02:13
la20	10	10	1180	0.31	00:33	1230	0.36	01:06	1134	0.26	01:39	1212	0.34	02:11
la21	15	10	1688	0.61	00:57	1561	0.49	01:54	1528	0.46	02:53	1577	0.51	03:53
la22	15	10	1497	0.61	00:58	1419	0.53	01:53	1447	0.56	02:56	1433	0.55	03:56
la23	15	10	1493	0.45	00:58	1516	0.47	01:54	1356	0.31	02:53	1544	0.50	03:52
la24	15	10	1464	0.57	00:57	1340	0.43	01:56	1424	0.52	02:52	1321	0.41	03:52
la25	15	10	1474	0.51	00:58	1399	0.43	01:56	1457	0.49	02:54	1489	0.52	03:53
la26	20	10	1875	0.54	01:26	1897	0.56	02:55	1861	0.53	04:23	1902	0.56	05:53
la27	20	10	2023	0.64	01:25	1993	0.61	02:51	2065	0.67	04:21	1974	0.60	05:49
la28	20	10	1936	0.59	01:25	1841	0.51	02:50	1865	0.53	04:18	1849	0.52	05:51
la29	20	10	1899	0.65	01:27	1839	0.60	02:51	1839	0.60	04:21	1851	0.61	05:51
la30	20	10	2007	0.48	01:24	1878	0.39	02:50	1975	0.46	04:19	1872	0.38	05:49
la31	30	10	2611	0.46	02:37	2483	0.39	05:23	2381	0.33	08:05	2512	0.41	10:57
la32	30	10	2733	0.48	02:36	2735	0.48	05:31	2722	0.47	08:18	2620	0.42	10:52
la33	30	10	2520	0.47	02:36	2386	0.39	05:17	2432	0.41	08:04	2438	0.42	10:57
la34	30	10	2502	0.45	02:36	2482	0.44	05:18	2464	0.43	08:03	2498	0.45	11:01
la35	30	10	2780	0.47	02:55	2782	0.47	05:20	2695	0.43	08:08	2677	0.42	10:57
la36	15	15	1919	0.51	01:31	1880	0.48	03:05	1889	0.49	04:41	1896	0.50	06:19
la37	15	15	2176	0.56	01:32	2163	0.55	03:06	2077	0.49	04:47	2077	0.49	06:26
la38	15	15	1902	0.59	01:34	1889	0.58	03:09	1868	0.56	04:43	1847	0.54	06:19
la39	15	15	1927	0.56	01:32	1870	0.52	03:05	1925	0.56	04:42	1904	0.54	06:21
la40	15	15	2058	0.68	01:33	1984	0.62	03:06	1906	0.56	04:40	1957	0.60	06:20

Table 1 shows the computational results of different instances. The best solution column (BS) denotes the minimum makespan, the relative percent error column (RE) denotes a percentage of best solution over best known solution, and the computation time column (CT) denotes an average CPU time.

5. CONCLUSION

The computational experiments show the efficiency of the algorithm in finding an optimum solution for difference size problems. Moreover, the particle swarm optimization is easy to implement and can be applied in the small and medium-sized enterprises which computer resources are limited. Future research

will modify the standard PSO and then address more challenging optimization problems in the real world.

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