Paper 30

by The Jin Ai

A Particle Swarm Optimization Algorithm for Solving Economic Lot Scheduling Problems

The Jin Ai †, Ririn Diar Astanti, Agustinus Gatot Bintoro
Department of Industrial Engineering, Faculty of Industrial Technology
Universitas Atma Jaya Yogyakarta, Indonesia
Tel: (+62) 274-487711 Fax: (+62) 274-485223
Email: jinai@mail.uajy.ac.id, ririn@mail.uajy.ac.id, a.bintoro@mail.uajy.ac.id

Dah Chuan Gong
Department of Industrial and Systems Engineering
Chung Yuan Christian University, Chung-Li, Taiwan
Email: gongdc@cycu.edu.tw

Abstract. The Economic Lot Scheduling Problem (ELSP) is the problem for determining the production schedule of many products to single production facility where the setup times, production and demand rates of each product are different. Due to its practical importance in the field of production and inventory management, this problem has been attracted many researchers and lead to many problem variants. Some exact and heuristics approaches had been proposed in the past for solving the ELSP and its variants, however, each approach is usually intended to solve a particular ELSP variant. This paper tries to develop a new and unified solution methodology for solving the ELSP and its variants using the particle swarm optimization, especially by proposing the solution representation and its decoding method. The computational results show that the proposed algorithm is able to find good solution of ELSP.

Keywords: Economic Lot Scheduling Problem, Production and Inventory Management, Particle Swarm Optimization, Computational Method, Metaheuristics

1. INTRODUCTION

The Economic Lot Scheduling Problem (ELSP) is the problem to determine the production schedule of several products to single production facility, where the setup times, production and demand rates of each product are different, to minimize the total cost per unit time. This problem is commonly appear in various type industries including plastic injection molding, automobiles, electronics, paints, textile, and pharmaceutical (Boctor, 1987; Gallego and Joneja, 1994). Due to its practical importance in the field of production and inventory management, this problem has been attracted many researchers and lead to many problem variants. Elmaghraby (1978), Lopez and Kingsman (1991), Silver et al. (1998), and Winands et al. (2011) have provided an excellent review of ELSP.

The basic or traditional version of ELSP can be formulated as follow. A single production facility produces m item of products, in which only one product can be produced at a time on the production facility. Each product i has a deterministic and constant demand rate (d_i) and production rate (p_i). The setup cost (A_i) and the setup times (s_i) of each product are independent of the production sequence. The production facility is assumed to be capable of satisfying demand predicted during the planning horizon. The decision variables of this problem are the production cycle of each product (T_i), in order to minimize the total production cost. The total production cost consists of setup cost and inventory holding cost (h_i) that can be formulated as follow

$$Z = \sum_i \frac{A_i}{T_i} + \frac{1}{2}\sum_i h_i d_i \left(1 - \frac{d_i}{p_i}\right) T_i \qquad (1)$$

Even for the basic version of ELSP, there are three different main scheduling policies for ELSP, namely, common cycle approach, basic period approach, and time-varying lot sizes approach. The common cycle approach applies the same cycle time for all products, i.e. $T_i = T$ for

† :Corresponding Author

all i (Khoury et al., 2001; Torabi et al., 2005; Moon et al., 2002a; Moon et al., 200b; Chatfield, 2007). In the basic period approach, the cycle time may different for different products, however, each cycle time must be an integer multiplication of the basic period (W), i.e. $T_i = n_i W$ where n_i is the integer multiplier for item i. A popular version of this approach is called power of two approach, in which the integer multiplier is selected to be the power of two (2^k) only instead of all integer number (Moon et al., 2002a; Moon et al., 2002b; Raza et al., 2006; Raza and Akgunduz, 2008). In the time-varying lot sizes approach, different lot sizes are possible for any given products in a cycle schedule (Dobson, 1987; Moon et al., 2002a; Moon et al., 2002b; Raza et al., 2006; Raza and Akgunduz, 2008).

While some basic versions of ELSP works with a lot of simplifying assumptions, ELSP research is also well developed in the complication versions with sophisticated mathematical model due to considering several real world situation, such as sequence dependent setup (Oh and Karimi, 2001; Wagner and Davis, 2002; Brander and Forsberg, 2005), stochastic demand (Winands et al., 2011), imperfect production facility (Kim et al., 1997; Khouja, 2000; Ma et al., 2010), and multi-stage production facility (Sun et al., 2009; Haksoz and Pinedo, 2011; Chan et al., 2012). Since these problem variants are more complex than the basic versions, the solution of these problem are difficult to obtain analytically. Therefore, various approximations, heuristics and metaheuristics approaches are being popular for solving these ELSP variants.

Some researchers have been trying to use particle swarm optimization (PSO) as one of the most widely applied metaheuristics for solving the ELSP. It is clearly seen from those examples that there are two disadvantages of those PSO application for ELSP: too complicated and problem dependent.

This paper is trying to develop a simple PSO algorithm for solving ELSP. Even it starts with the PSO for basic ELSP, by focus on the common cycle approach and basic period approach, the algorithm is expected to be a foundation for more complex ELSP variants, i.e. there is no substantial and significant adjustment whenever more complex ELSP variants are being solved with the proposed PSO for basic ELSP.

The remainder of this paper is organized as follows: Second section is review some basic PSO. After that the PSO algorithm for common cycle approach and basic period approach are proposed in section 3 and 4, respectively. The following section presents a computational test of the proposed algorithms. Finally, some the conclusion of this study is presented with some suggestions for further research in this research area.

2. PARTICLE SWARM OPTIMIZATION

In 1995, Kennedy and Eberhart proposed the Particle Swarm Optimization (PSO) after gets some inspiration from the behavior of swarm organism such as bee swarm, fish school, and bird flock. The PSO is then proposed as a population-based stochastic optimization technique, by mimics the physical movement of individuals in the swarm to conduct the search mechanism of problem solution. For representing individuals in the swarm, an object called particle is defined along with its two important properties of particle namely position and velocity.

A particle position, which is usually placed in multi-dimensional space, represents an alternative of problem solution. Velocity of particle is the driver of particle movement from one position to another. In the PSO, particle movement represents evaluation process of alternatives of problem solution. In other words, the particle velocity expresses the searching capability of the problem solution.

There are two important behaviors of the swarm organism that are formulated in the PSO, namely the cognitive behavior and the social behavior. The cognitive behavior is defined as the tendency of particle moving towards the best position ever visited by the particle, which is usually called personal best or pbest. While the social behavior is defined as the tendency of particle moving towards the best position ever visited by all particles in the swarm, which is usually called personal best or pbest. The movement of particles can be stated as following equations:

$$\omega_{lh}(\tau+1) = w(\tau+1)\omega_{lh}(\tau) + c_p u(\psi_{lh}-\theta_{lh}(\tau)) + c_g u(\psi_{gh}-\theta_{lh}(\tau)) \quad (2)$$

$$\theta_{lh}(\tau+1) = \theta_{lh}(\tau) + \omega_{lh}(\tau+1) \quad (3)$$

where τ is iteration index, l is particle index, h is dimension index, u is uniform random number in interval [0,1], $w(\tau)$ is inertia weight in the τ^{th} iteration, $\omega(\tau)$ is velocity of l^{th} particle at the h^{th} dimension in the τ^{th} iteration, $\theta(\tau)$ is position of l^{th} particle at the h^{th} dimension in the τ^{th} iteration, ψ_{lh} is personal best position (pbest) of l^{th} particle at the h^{th} dimension, ψ_{gh} is global best position (gbest) of l^{th} particle at the h^{th} dimension, c_p is personal best acceleration constant, and c_g is global best acceleration constant.

In general, the algorithm of PSO can be formally defined as follow:

1. initialization of particles, their position and initial velocity,
2. decode particles into problem solutions,
3. evaluate the quality of particles, based on their corresponding objective functions,
4. update pbest value,
5. update gbest value,
6. update velocity and position for each particle, i.e. based

equations 2 and 3,

7. if the stopping criterion, i.e. maximum number of iteration, is reached, stop. Otherwise return to step 2.

Based on the algorithm above, at the end of iteration, the best problem solution is represented by the global best. Excellent review on the PSO methodologies and applications can be found in Kennedy and Eberhart (2001) and Clerc (2006). The algorithm is able to apply for solving various types of problems by defining the solution representation, that is how the particle represents the problem, which is usually called the solution representation, and how the particle can be translated into problem solution, which is usually called the decoding method. Therefore for applying PSO for ELSP, we need to define the solution representation and the decoding method in the following subsections.

3. PSO FOR COMMON CYCLE APPROACH

The common cycle approach applies the same production cycle time for all products, that is $T_i = T$ for all i. Therefore, if it is defined $\rho_i = d_i/p_i$, the optimization problem can be expressed as

$$\min Z(T) = \frac{\sum_i A_i}{T} + \frac{\sum_i h_i d_i (1-\rho_i) T}{2} \tag{4}$$

subject to

$$T \geq \sum_i s_i \Big/ \left(1 - \sum_i \rho_i\right) \tag{5}$$

The equation (5) guarantees the capability of production facility to satisfy demand predicted during the planning horizon. Two conditions should be considered for this guarantee: the total setup and production uptime of all item should be less than or equal to the production cycle and the demand of each item i has to be equal with the production of its corresponding item over the production cycle time. If τ_i is defined as the production uptime of item i, these two conditions can be written as

$$\sum_i s_i + \sum_i \tau_i \leq T \tag{6}$$

$$d_i T = \tau_i p_i \tag{7}$$

By simple algebra, i.e. after solving equation (7) for τ_i and substituting the expression to equation (6), we can easily proof the expression in equation (5).

Therefore, it is easily seen that the ELSP with common cycle approach is a single variable optimization with decision variable T. In order to apply PSO for solving ELSP with common cycle approach, the solution representation is a single dimension particle in which the position of the particle is defined as real value number. This real value number can be directly transformed into the decision variable T. Figure 1 illustrates the transformation of particle position into the decision variable.

dimension	1
position	1.52

→

solution	
T =	1.52

Figure 1: Solution representation and its conversion to T.

For the effectiveness of the searching process, we may set the lower bound of searching (the minimum value of particle position) based on equation (5) and the upper bound of searching (the maximum value of particle position) is the largest value among the independent solution of item i. It is noted that from the ELSP early references (i.e. Elmaghraby, 1978), the independent solution T_i is obtained by solving independently for each item i its corresponding cost, which can be formulated by following objective function

$$\min Z_i(T_i) = \frac{A_i}{T_i} + \frac{h_i d_i (1-\rho_i) T_i}{2} \tag{8}$$

The solution of equation (8) can be found using classical optimization method, that is by setting the necessary optimality condition of $dZ_i/dT_i = 0$. Therefore the lower and upper bound of searching for T can be written as

$$T_{\min} = \sum_i s_i \Big/ \left(1 - \sum_i \rho_i\right) \tag{9}$$

$$T_{\max} = \max_i \left\{ \sqrt{\frac{2A_i}{h_i d_i (1-\rho_i)}} \right\} \tag{10}$$

4. PSO FOR BASIC PERIOD APPROACH

In the basic period approach, production cycle of each product is the multiplication of basic period (W), that is $T_i = n_i W$. Therefore, the total production cost can be written as

$$Z(T_i) = \sum_i \frac{A_i}{T_i} + \frac{1}{2} \sum_i h_i d_i (1-\rho_i) T_i \tag{11}$$

or

$$Z(W, n_i) = \sum_i \frac{A_i}{n_i W} + \frac{1}{2} \sum_i h_i d_i (1-\rho_i) n_i W \tag{12}$$

A very tight feasibility condition of this approach can be stated as

$$\sum_i s_i + \sum_i \rho_i n_i W \le W \tag{13}$$

This condition is based on the worst case possibility of producing all products in at least single cycle. However, this condition is excessive since only if all $n_i = 1$, there always a cycle producing all products. Otherwise, there is a possibility to schedule products such that not producing all products in every cycle.

Chatfield (2007) formulated the problem with additional decision variables b_i in which defined as the starting period of item i. Based on n_i and b_i, we can identify what items produced in each cycle 1, …, M; in which M is the least common multiplier of all n_i. Therefore, the feasibility checking can be done in each cycle j, j =1, …, M by following formula

$$\sum_{i \in I_j} \left(s_i + \rho_i n_i W \right) \le W \tag{14}$$

in which I_j is the set of item i that being produced in cycle j. Based on this idea, the ELSP with basic period approach can be considered as an optimization problem with $2m$+1 variables.

We are proposing a solution representation for ELSP with basic period approach with $2m$+1 dimensions, all are real number within the interval [0, 1]. The dimensions are categorized as follows:

- First m dimensions of particles are for n_i
- Next m dimensions of particles are for b_i
- Last dimension of particles is for W

The decoding method which translates particle position into ELSP solution is defined using following equations:

$$n_i = \lceil x_i n_{\max} \rceil \tag{15}$$

$$b_i = \lceil x_{m+i} n_i \rceil \tag{16}$$

$$W = x_{2m+1} T_{CC} \tag{17}$$

where $n_{\max}$ is defined as the largest value of n_i and T_{CC} is the common cycle time period. Using this definition, in other words, the value of n_i is an integer number in the range of [1, $n_{\max}$] and the value of b_i is an integer number in the range of [1, n_i]. Figure 2 illustrates the transformation of particle position into the decision variables.

We can slightly modify this definition for applying the power of two approach, which is $n_i = 2^k$, by replacing equation (15) with this equation

$$n_i = 2^{\lfloor x_i k_{\max} \rfloor} \tag{18}$$

The advantage of using power of two approach is we can set the value of M by the biggest n_i, instead of finding the least common multiplier of all n_i.

dimension	1	2	3	4	5	6	7
position	0.52	0.94	0.03	0.35	0.69	0.37	0.29

variable	n_1	n_2	n_3	b_1	b_2	b_3	W
value	5	8	1	2	6	1	11.6

Figure 2: Solution representation of ELSP with 3 items product and its conversion to the decision variables (with $n_{\max}$ = 8 and T_{CC} = 40).

5. COMPUTATIONAL TEST

In order to evaluate the proposed solution representation, a computational test is conducted by using the Bomberger problem, in which a metal stamping machine that must be used to produce 10 different products. The details of this problem can be found easily in several ELSP references, including Chatfield (2007), therefore it is not necessary to rewrite the details in this paper.

The PSO algorithm and the proposed decoding methods are implemented using C# language and supported by PSO computational library called ET-Lib (Nguyen et al., 2010). It is noted that the ET-Lib uses a PSO variant called GLNPSO that has three different social behavior terms called global best, local best, and nearest neighbor best with its corresponding acceleration constant (c_g, c_l, and c_n). All the test instances are run on a computer with an Intel i5-2410M @ 2.30 GHz CPU and 4 GB RAM.

5.1 Test for Common Cycle Approach

The computational test for the common cycle approach are using following PSO parameters: number of particle 30, number of iteration 1000, number of neighbor 5, $w_{\max}$ = 0.9, $w_{\min}$ = 0.4, c_p = 1, c_g = 1, c_l = 1, c_n = 1, and 10 replication runs of the algorithm is conducted. The results is very consistent, all replications can obtain the same result, which is T = 42.754 days and $Z(T)$ = \$ 41.1657/day or \$ 9879.77 /year. This result is also similar with the optimal result in the existing literature (i.e. Elmaghraby, 1978).

Figure 3 shows the progress of the best objective function value in the first 100 iterations of a replication. It shows that actually the best objective function for whole iterations is actually found before iteration number 20. In other word, the optimal solution of this problem can be found within small number of iteration. Therefore, actually it is not necessary to use 1000 iterations for this problem.

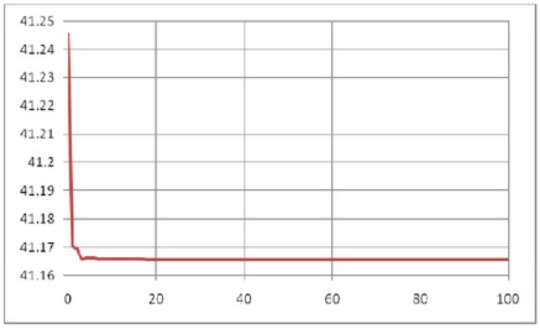

Figure 3: The best objective function value across iterations.

5.2 Test for Basic Period Approach

The computational test for the basic period approach are using following PSO parameters: number of particle 100, number of iteration 2000, number of neighbor 5, w_{max} = 0.9, w_{min} = 0.4, c_p = 1, c_g = 1, c_l = 1, c_n = 1, and 10 replication runs of the algorithm is conducted. We are using directly the power of two approach, for avoiding the additional effort to compute the least common multiplier in the feasibility checking of each solution. The value of k_{max} and T_{CC} are selected to be 5 and 41, respectively. The computational results of each replication are presented in Table 1, while the details on the decision variables of the best found solution (which is in the replication 7) is presented in Table 2.

It is noted that the best solution found by the PSO (with Z = 7697.09) is also consistent with the best found solution from other literature (see Chatfield, 2007). Some variations among the results are shown by this proposed algorithm, however, the average deviation from the best found solution is not more than 5%.

Table 1: Computational result of basic period approach

rep	W	Z ($/day)	Z ($/year)
1	29.08	34.60	8304.25
2	29.19	34.60	8304.75
3	33.98	35.24	8457.43
4	24.21	32.21	7730.86
5	29.08	34.60	8304.25
6	12.37	33.44	8025.83
7	**23.42**	**32.07**	**7697.09**
8	25.49	32.20	7728.29
9	25.56	32.90	7894.96
10	29.19	34.60	8304.75

Table 2: Detail of the decision variables on the best found solution

item	n_i	b_i
1	8	4
2	2	1
3	2	1
4	1	1
5	2	1
6	4	2
7	8	8
8	1	1
9	2	2
10	2	1

6. CONCLUDING REMARK

This paper is successfully presented that a simple version of PSO is able to solve the ELSP using the common cycle and basic period approaches. Fine tuning the algorithm for the basic period approach is still required in order to increase the consistency of the computational results. Some significant effort is still needed for developing the PSO for ELSP with time-varying lot sizes approach. This proposed PSO algorithm for common cycle and basic period approaches are ready to be applied for more complex ELSP variants using respective approaches, including ELSP with imperfect production system.

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