

Ant Colony Optimization for Load Management Based on Load Shifting in the Textile Industry

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Abstract: The textile industry is a complicated manufacturing industry because it is a fragmented and heterogeneous sector dominated by Small and Medium Enterprises (SMEs). There are various energy-efficiency opportunities that exist in every textile plant. However, even cost-effective options often are not implemented in textile plants mostly because of limited information on how to implement energy-efficiency measures. This paper presents the expansion of problem formulation of consummation management based on load shifting in textile industry. The mathematical model is a Non Polynomial (NP) hard optimization problem to determine the start time of the process in order to minimize the total electricity cost under varying tariffs such as flat rate and Time of Use (TOU). For solve this problem, Ant Colony Optimization (ACO) is applied and compared with Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). To show its efficiency, the case studies in case of Single Process Multiple Jobs (SPMJ) in term of small, medium and large scales are demonstrated. The results show that the proposed method is able to achieve the best solution efficiently and easy to implement.

Keywords: Load Management, Time of Use, Ant Colony Algorithm, Textile Industry Optimization

Introduction

The textile industry is one of the most convoluted contemporary industries because it is a fragmented and heterogeneous sector dominated by Small and Medium Enterprises (SMEs). Characterizing the textile manufacturing industry is composite because of the wide variety of substrates, processes, machinery and apparatus used and finishing steps undertaken. Different types of fibers or yarns, methods of fabric production and finishing processes (preparation, printing, dyeing, chemical/mechanical finishing and coating), all correlate in producing a finished fabric. Electrical energy is one of the main cost factors in the textile industry. Especially in times of high energy price volatility, improving energy-efficiency should be a primary concern for textile plants. There are various energy-efficiency opportunities that exist in every textile plant, many of which are cost-effective. However, even cost-effective options are not

often implemented in textile plants mostly because of limited information on how to implement such energy-efficiency measures, especially given the fact that a majority of textile plants are categorized as SMEs and hence they have limited resources to acquire this information. Know-how on energy-efficiency technologies and practices should, therefore, be prepared and disseminated to textile plants. An extensive literature review was conducted in this study to collect information on the energy use in and energy efficiency measures/technologies for the textile industry (Ashok and Banerjee, 2000). In recent years; various Load Management (LM) programs are used by electric utilities to tackle the peak load problem (Ashok and Banerjee, 2003). LM is the strategies, reported with potential reduction in system peak demand with different LM (Sheen *et al.*, 1994). Many the utility, have the reduction in peak demand improves the utilization of base load generating stations and avoids costly peaking stations

and other device in their service area (Cohen and Wang, 1988). The customer benefits, as there is reduction in the energy cost bill. To promote LM, utilities offer incentives like Time of Use (TOU) rates (Ashok, 2006). The textile plants being the bulk consumers, the contact of LM action like load scheduling under TOU tariff on peak demand reduction is high. The textile industries can also control their energy costs by optimal load schedule under TOU tariff. The production-scheduling problem in textile manufacturing, as a multi-stage job shop scheduling problem, is also reported (Laoboonlur, 2004). Most of the models for textiles are centered on process scheduling to achieve the targeted production subject to production constraints and do not give the impact on peak electricity-demand reduction. The optimal schedule to reduce the peak utility load is reported for production processes considering cost worker and process constraints. Extending this work, a production process model coupled with an optimization formulation for process industries with jobs and continuous type loads is presented here to prescribe optimal load-schedule strategies under different tariff structures. The industries can also control their electricity costs by optimal load schedule under TOU tariff. Load Shifting (LS) is a basic method for adapting load curves so as to reduce marginal costs of electric power supply. Load shifting within textile industry is based on their inhabitant behavior and in their equipment. Thus, we have to account for both (Bremer *et al.*, 2008) the practice of managing electricity supply and demand so that peak energy use is shifted to off-peak periods. Properly done, load shifting helps meet the goals of improving energy efficiency and reducing emissions by smoothing the daily peaks and valleys of energy use and optimizing existing generation assets. Load shifting may be accomplished in several ways. Demand response programmers shift load by controlling the function of machine production, water heaters, heat pumps and similar electric loads at maximum demand times. The goal of this paper is to develop the ACO algorithm for solving the load shifting problem. Firstly, the load scheduling problem consisting of small, medium and large jobs which considers the applied to determine the start time of the process in order to minimize the total electricity cost under varying tariffs such as flat rate and Time of Use (TOU). To show its efficiency, the case studies in case of Single Process Multiple Jobs (SPMJ) are studied. The results optimized by the ACO are compared to those obtained by the conventional approaches, i.e., GA and PSO in terms of solution quality and computational efficiency.

The paper is organized as follows: Section 2 problem formulation deals with the design principles of LS jobs scheduling on machine production. Section 3 describes the basics of Ant Colony System. Section 4 demonstrates the experimental setup deals with the results and discussions and conclusions are drawn in section 5.

Overview and Problem Formulation

Textile Process

Figure 1 is a generalized flow diagram depicting the various textile processes that are involved in converting raw materials into a finished product. All of these processes do not occur at a single facility, although there are some vertically integrated plants that have several steps of the process all in one plant. There are also several niche areas and specialized products that have developed in the textile industry which may entail the use of special processing steps that are not shown in Fig. 1:

- Spun yarn spinning
- Weaving
- Wet-processing (preparation, dyeing, printing and finishing)
- Man-made fiber production

Types of Energy Used in Textile Industry

In general, energy in the textile industry is mostly used in the forms of: Electricity, as a common power source for machinery, cooling and temperature control systems, lighting, office equipment, etc.; oil as a fuel for boilers which generate steam; liquefied petroleum gas; coal; and city gas. The rational use of energy calls for a broad application of energy conservation technologies in the various industrial sectors where energy is wasted. One of these energy intensive industrial sectors to be considered to improve efficiency through the introduction of modern energy conservation technologies is the textile industry. In the textile industry, appreciable amounts of energy could be saved or conserved by regulating the temperature in the steam pipes, adjusting the air/fuel ratio in the boilers and installing heat exchangers using warm waste water.

Load Pattern and Electrical Tariffs in Thailand

Domestic consumption in 1991 could be divided into three periods of time, i.e., during the evening time hours of 6:30 to 9:30 pm when the power consumption was highest (peak period), during the daytime hours of 8:00 am to 6:30 pm when the consumption was moderate (partial-peak period) and during the night-time and early morning hours of 9:30 pm to 8:00 am when the consumption was low (off-peak period). During the peak period, the Electricity Generating Authority of Thailand (EGAT) had to use its full generation capacity until the minimum reserve margin was reached; the Provincial Electricity Authority (PEA) had to use its full dispatching capacity in the same period, whereas the Metropolitan Electricity Authority (MEA) had to maximize its dispatching capacity in the afternoon when the consumption nationwide was at moderate level.

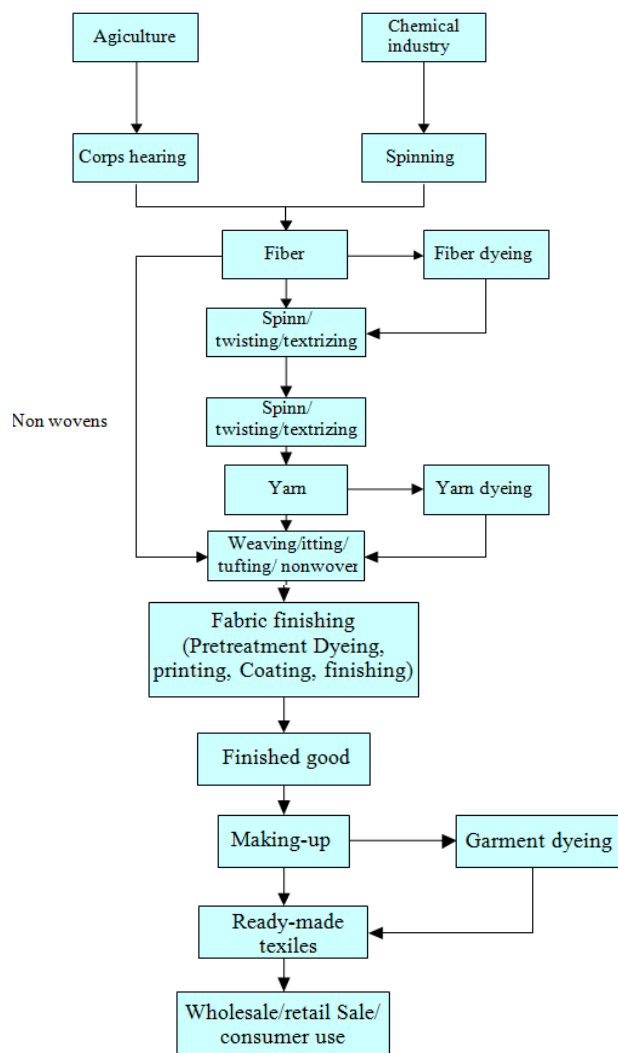


Fig. 1. Textile process

Therefore, if the demand had increased during the peak period, the power sector would have been required to increase the investment in power generation and distribution. Both from an energy efficiency perspective and from equity of rates perspectives, large consumers during the peak period should pay a higher tariff than small consumers during the off-peak period of the system. One way to determine a fair tariff was to use a formula to automatically adjust the electricity charges in different periods of a day, i.e., implement a Time-of-Day (TOD) Rate. However, this method could not be applied to all individual consumers because the expense for meter installation was rather high.

The TOD Rate or Flat Rate

The TOD Rate is the electricity tariff rate that varies with the time-period during which electricity has been used during the day. Its objective is to shift consumption from the peak to off-peak periods. The TOD Rate was

first used in Thailand in 1964 as an alternative rate applied to the industrial sector. In 1966 it became one of the alternative rates for customers that were served directly by EGAT. In practice, only a few customers opted into this rate.

Time-of-Use (TOU) Rate

The Time-of-Use Rate (TOU) was established as an alternative for users who currently use the TOD rate so that the tariff structure would reflect the costs and load curve of the system. As of September 1998, 167 customers were on TOU rates, of which 11 were in MEA and 156 in PEA. The TOU rate differs from the TOD rate in the following: TOU will increase tariff categories for consumers whose consumption is at or greater than 115 kV; the tariff will be lower than that of the previous 69 kV. TOU will be divided into two periods of time, i.e., peak, from 9 am to 10 pm on Mondays through Saturdays and off-peak during all other hours. Under the TOU rate, the energy charge varies according to voltage levels and periods of time. Under the TOU rate, there is no demand charge during the Off-Peak period. The newly established TOU rate will be compulsory for new consumers who have to use the TOD rate. The TOU rate best reflects actual costs of the current power system. This will provide more incentives for consumers to change their consumption behavior, whereas those whose consumption is consistent and who do not change their consumption behavior will not be harmed.

The research for electrical tariff to major industrial sector may consist of a charge for the total kWh consumed, a power factor charge and a kW maximum demand charge.

The costs of the total electrical energy before shifting and after shifting are calculated with the TOU tariff rate applying by the MEA rated voltage is 24 kV connected grid. The tariff for the industrial sector is TOD rate or late rate as shown Table 1 and TOU rate shown in Table 2.

Load Shifting Problem Formulation

In this section, the load management based on load shifting for the textile process is presented. The problem can explain in 3 parts; systematic model, feasible solution structure, fitness function.

Systematic Model

Systematic model of load shifting for the textile process can be explained in four parts which are input parameters, decision variables, constraints and system output as shown in Fig. 2.

Input Parameters

The input parameters consist of the step of textile production process, process and transfer time, number of machine and man power of each step, rated power each of machines. The input varies depending on the of production process type.

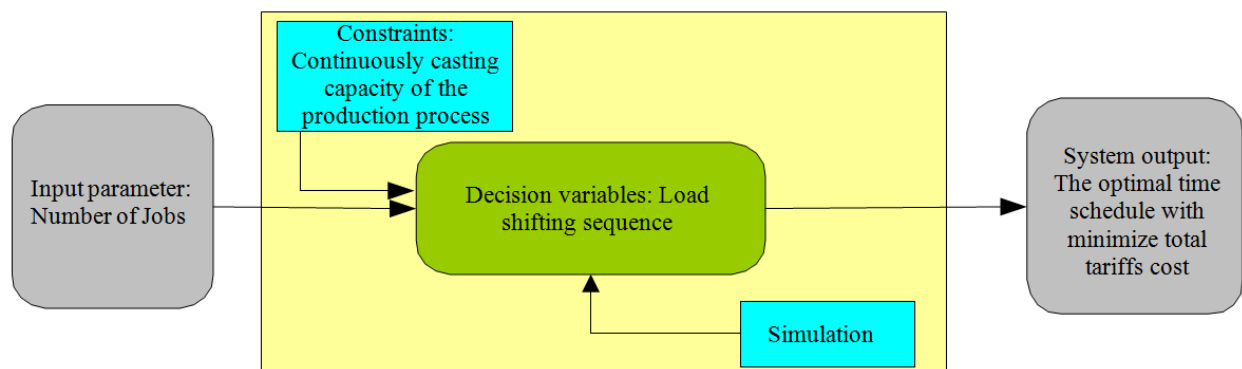


Fig. 2. Systematic model of load shifting problem

Table 1. The Time-of-Day (TOD) rate in Thailand

Time of day rate (Tariff)	Demand charge (Baht/kW)			Energy charge (Baht /kWh)
	1*	2*	3*	
69 kV.and over	224.30	29.91	0	1.6660
12-24 kV.	285.05	58.88	0	1.7034
Below 12 kV.	332.71	68.22	0	1.7314

Flat rates or Time-of-Day (TOD Tariff): Demand charge: 1.7034 Bath /kWh or (0.052\$/kWh)), Energy charge: 58.88 Bath/kW or (1.84\$/kWh)), (Note: Present transaction rate 1 US\$:bath. 32.0

On Peak: Everyday from 06.30 to 09.30 PM, Partial Peak: Everyday from 08.00 to 06.30 PM (only the amount of maximum demand that is out of the On-Peak period will be charged at this rate).

*Off Peak: Everyday from 09.30 to 08.00 AM (No demand charge)

Table 2. Time of use tariff (TOU tariff)

Time of use (Tariff)	Demand charge (Baht/kW)		Energy charge (Baht/kWh)		Service charge (Baht/month)
	1*	1*	2*	2*	
69 kV and over	74.14	2.6136	1.1726	1.1726	228.17
12-24 kV.	132.93	2.6950	1.1914	1.1914	228.17
Below 12 kV.	210.00	2.8408	1.2246	1.2246	228.17

Time of Use tariff (TOU tariff), Demand Charge: 132.93 Bath/kW or (4.15\$/kW), Energy Charge: 1.1914 Bath/kWh or (0.037\$/kWh), On Peak: Monday-Friday from 09.00 to 10.00 PM off Peak: Monday-Friday from 10.00 to 09.00 AM, Saturday-Sunday and normal public holiday (excluding substitution holiday) from 00.00 AM to 12.00 PM.

*On Peak: Monday-Friday from 09.00 to 10.00 PM,*Off Peak: Monday-Friday from 10.00 PM to 09.00 AM Saturday-Sunday and normal public holiday (excluding substitution holiday) from 00.00 to 12.00 PM.

Decision Variables

The starting time of each job are assigned to decision variable. This variable will be used to determine the time schedule to minimize total energy cost.

Production Constraints

Normally, the textile industries have the specific machine and man power. The process cannot operate if the machine and man power are not available. Therefore, the constrains of time dispatching are limited by the of machine and manpower of industry.

System Output

The objective of load shifting scheduling is to minimize the total energy cost of process time schedule.

Structure and Feasible Solution

In this study, the structure of an solution for load shifting problem is composed of a set of starting time number each job. Therefore, size of solution is $1 \times n$ matrix where n is number of jobs. Note that it is very important to create a set of solution satisfying the constraints it is called a feasible solution.

The feasible solution of candidate solution is related to the of possible jobs, which can be found by

$$FS = T^n \quad (1)$$

Where:

FS = Number of feasible solution
 T = Number of time periods.

Fitness Function

In order to evaluate fitness function of load shifting problem, firstly define indices, parameters and decision variables as follows.

Indices:

i : Index of job, $j \in \{1, n\}$
 j : Index of the production process, $j \in \{1, m\}$
 t : Index of load shifting time schedule from job i to production process j , $t \in \{1, n\}$

Variables:

M : Number machine of production process.
 n : Number of job.
 PT_j : Process time of production process j
 NM_j : Number of machines of production process j
 NE_j : Number of manpower of production process j
 TT_j : Transfer time of production process j
 MP_j : Rated power machine of production process j
 ST_j : Start time of job i
 ST_{j-1} : Stop time of job $j-1$
 $Start_time_{ij}$: Start time of job i and process j
 $Stop_time_{ij}$: Stop time of job i and process j
 T : Time interval
 R_T : Tariffs cost rate of time interval

The $Start_time_{ij}$ is the present time $Start_time_{ij}$ is the time at which the m_n machines are set operational:

$$Start_time_{ij} = \begin{cases} ST_i & j = 1 \\ toptime_{ij-1} + TT_j & j = 2 \dots m \\ & i = 1 \dots n \\ & j = 2 \dots m \end{cases} \quad (2)$$

The $Start_time_{ij}$ is the stop present time; $Stop_time_{ij}$ is the time at which the m_n machines are not set operational as:

$$Stop_{time_{ij}} = Start_{time_{ij}} + PT_j \quad (3)$$

Total energy consumption of machines is obtained by summing the energy consumptions of all machines operating in the textile manufacturer. Certain machines processes have the feature of having multiple duty cycles. These machines have the capability to operate for different levels of power consumption. Energy consumption of given equipment for a particular period of time can be stated as:

$$E_{NMj} = P_{NMj} \times T \times R_T \quad (4)$$

where, E_{NMj} is the energy consumption of the NM_{ij} machines P_{NMj} is power consumption at T time interval is the time at which the NM_j machines are set operational. The cost of electricity consumption of given equipment is dependent on various factors including locality, watts, time of consumption and the cost-rate (peak versus non-peak hour) for that particular time of the day. The procedure of fitness function is given as follow. The information data for load shifting management problem is shown in Table 3. Here, the production process has 10 steps for plant textile in Thailand. This information will be used to convert a feasible solution or sequence to a time schedule for reduces energy power consumption.

Step1: Determine starting time and stop time of job i and process j . The step to find starting time of job i start with the computing Equation (2) and to find stop time as Equation (3)
 Step2: Determine time interval of each process and evaluate rate of tariff based on Tariff of use.
 Step3: Evaluate tariff cost by Equation (4) and energy cost of process at time interval

Case Study

To illustrate the model proposed, a case study has been worked out for a typical the dyeing machines of production process for 10 steps of textile process Samutsakorn province in Thailand. The connected load of the plant is 22 kV and transformer rated power is 2500 kVA, 0.400/230 V. Average daily electricity consumption is 2200 kWh. The plant has an automatic power factor correction unit which maintains the power factor nearly unity. For Example, assumed a solution is [8, 8, 8], First step, form Table 3, the column number of machines of plant defined as [2, 3, 4, 2, 4, 2, 2, 4, 3, 4] transform given by matrix $4 \times 10 =$

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \end{bmatrix}$$

Checked condition, If the total status of machine job i and process the column shown status is $1 \geq 1$, status is available, but the total status of machine job i and process is $= 0$, defined the machine cannot operated.

Step 2, determine starting time and stop time of job i and process j . The step to find starting time of job i start with the computing Equation 5:

$$Start_time_{ij} = \begin{cases} ST_i & j = 1 \\ toptime_{ij-1} + TT_j & j = 2 \dots m \\ & i = 1 \dots n \\ & j = 2 \dots m \end{cases} \quad (5)$$

Table 3. The dyeing machines of production process for 10 steps

Steps	Process time (min)	No. Machine plant	Transfer time	Machine kW/No.
Fabrics prepare	75	2	15	84
Dyeing, thies	60	3	10	105
Preset	100	4	15	123
Fabric prepare	90	2	10	94
Dying	150	4	20	117
Ring spinning	130	2	10	100
Rewinding	60	2	15	94
Heat setting	100	4	20	134
Inspection	60	3	10	78
Packing	95	4	15	85

(Table 3: Shown the textile process in Thailand)

Table 4. Time Scheduled of jobs 1, 2, 3 for load shifting technique

Jobs process	1	2	3	4	5	6	7	8	9	10
Job # 1										
Start time	8:00	9:30	10:40	12:35	14:15	17:05	19:25	20:40	22:40	23:50
Stop time	9:15	10:30	12:20	14:05	16:45	19:15	20:25	22:20	23:40	01:25
Job # 2										
Start time	8:00	9:30	10:40	12:35	14:15	17:05	19:25	20:40	22:40	23:50
Stop time	9:15	10:30	12:20	14:05	16:45	19:15	20:25	22:20	23:40	01:25
Job # 3										
Start time	9:30	11:00	12:10	14:15	15:55	19:25	21:45	23:00	01:00	02:10
Stop time	10:45	12:00	13:50	15:45	18:25	21:35	22:45	00:40	02:00	03:45

Table 5. The result of energy cost power consumptions load-shifting technique for case study

Job process	1	2	3	4	5	6	7	8	9	10	Total energy cost (Baht)
Job1	155.6762	282.9750	552.4750	379.9950	788.2875	583.9167	253.3300	534.7225	92.9292	160.3426	3785.6
Job2	155.6762	282.9750	552.4750	379.9950	788.2875	583.9167	253.3300	534.7225	92.9292	160.3426	3785.6
Job3	282.9750	282.9750	552.4750	379.9950	788.2875	583.9167	147.3262	266.0793	92.9292	160.3426	3537.3
Total energy cost (Baht)											11109.5

If process can not available to find stop time as equation, minimize:

$$(Stop_time_{ki})_{i=1...n,k'i}$$

The results of this step are shown in Table 4.

Step3: Evaluate tariff cost by Equation (4) and energy cost of process at interval time. The results of this step are shown in Table 5.

Ant Colony Optimization

Inspired by the collective behavior of a real ant colony, Marco Dorigo first introduced the Ant System (AS) in his Ph.D. thesis (1992) and Dorigo *et al.* (1996) further continued the study (Colorni *et al.*, 1991). The characteristics of an artificial ant colony include positive feedback, distributed computation and the use of a constructive greedy heuristic. Positive feedback accounts for rapid discovery of good solutions, distributed computation avoids premature convergence and the greedy heuristic helps to find acceptable solutions in the

early stages of the search process. In order to demonstrate the AS approach, the authors apply this approach to the classical TSP, asymmetric TSP, Quadratic Assignment Problem (QAP) and job-shop scheduling. The AS shows very good results in each applied area. More recently, Dorigo and Gambardella have worked on extended versions of the AS paradigm. ACO is the one of the extensions and has been applied to the symmetric and asymmetric TSP with excellent results (Dorigo *et al.*, 1996). The Ant System has also been applied with success to other combinatorial optimization problems such as the vehicle routing problem (Dorigo and Gambardella, 1997a; 1997b).

ACO is an algorithm that was inspired by the behavior of real ants. Ethnologists have studied how blind animals such as ants capable of finding the shortest path from food sources to the nest without using visual cues. They are also capable of adapting to changes in the environment. For example, finding a new shortest path once the old one is no longer feasible due to a new obstacle. The studies of ethnologists reveal that such capabilities are essentially due to communicating information among individuals regarding path to decide

the direction. Ants deposit a certain amount of pheromone while walking and each ant probabilistically prefers to follow a direction rich in pheromone rather than a poorer one.

The process can be clearly illustrated by Fig. 3a ants are on a straight line that connects a food source to their nest. An ant will deposit pheromone while walking and it probabilistically prefers to follow a direction rich in pheromone.

This behavior can be explained how ants can find the shortest path that reconnects a line that is broken by an obstacle in Fig. 3b. On introducing, those ants are just in front of the obstacle and they cannot continue to go. Therefore, they have to choose between turning right or left. Half the ants choose to turn right and the other half choose to turn left. A similar situation arises on the other side of the obstacle Fig. 3c. Ants choose the shorter path will more rapidly reconstitute the interrupted pheromone trail compared with those choosing the longer path. Thus, the shorter path will receive a greater amount of pheromone per time unit and, in turn, larger number of ants will choose the shorter path. Due to this positive feedback, all the ants will rapidly choose the shorter path Fig. 3d. All ants move approximately the same speed and deposit a pheromone trail at approximately the same rate. The time consumed on the longer side of an obstacle is greater than the shorter path. It thus makes the pheromone trail accumulate more quickly on the shorter path. Moreover, ants prefer higher number of pheromone trail that causes accumulation can be built up faster on the shorter path.

In general, the procedure of ACO algorithm can be described as follows: m ants are initially positioned at the nest. Each ant will choose a possible route as a solution. In fact, each ant builds a feasible solution (called a tour) by a stochastic greedy search, called; *the state transition rule* is repeatedly applied. Once all ants have terminated their tours, the following steps are performed.

The amount of pheromone is modified by applying the *global updating rule*. Ants are guided, in building their tours, by both heuristic information and pheromone information. Naturally, a link with a high amount of pheromone is a desirable choice. The pheromone updating rules are designed so that they tend to give more pheromone to edges, which should be visited by ants.

A flowchart of a conventional ACO algorithm is shown in Fig. 4.

The detail of ACO algorithm can be described in the following steps:

Step 1 Initialization
 Set NC = 0 /* NC: cycle counter */
 For every combination (i,j)
 Set an initial value $\tau_{ij}(0) = \tau_0$ and $\Delta\tau_{ij} = 0$
 End

Step 2 Construct feasible solutions
 For k=1 to m /* m: Number of ants */
 For i=1 to n /* n: Number of links */
 Choose a level of connection with transition probability given by Equation (6).
 End
 Calculate fitness function f_k /* f_k : Fitness value of each ant */
 End
 Update the best solution
 Step 3 Global updating rule
 For every combination (i,j)
 For k=1 to m
 Find $\Delta\tau_{ij}^k$ according to Equation (10)
 End
 Update $\Delta\tau_{ij}$ according to Equation (9)
 End
 Update the trail values according to Equation (9)
 Update the transition probability according to Equation (6)
 Step 4 Next search
 Set NC = NC+1
 For every combination (i,j)
 $\Delta\tau_{ij} = 0$
 End
 Step 5 Termination
 If (NC < NC_{max})
 Then
 Goto step 2
 Else
 Print the best feasible solution
 Stop
 End
 End

State Transition Rule

The state transition rule of the ant colony is given in Equation (6). This equation represents the probability that ant k selects a link connects node i and node j :

$$p_{ij}^k(t) = \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}(t)]^\beta}{\sum_{m=1}^{M_i} [\tau_{im}(t)]^\alpha [\eta_{im}(t)]^\beta} \quad (6)$$

where, τ_{ij} is the pheromone intensity and η_{ij} is the heuristic information between node i and node j , respectively. In addition, α is the relative importance of the trail and β is the relative importance of the heuristic information. The problem specific heuristic information is:

$$\eta_{ij} = \frac{1}{C_{ij}} \quad (7)$$

where, C_{ij} represents the associated cost. Therefore, the level of link with smaller cost has greater probability to be chosen.

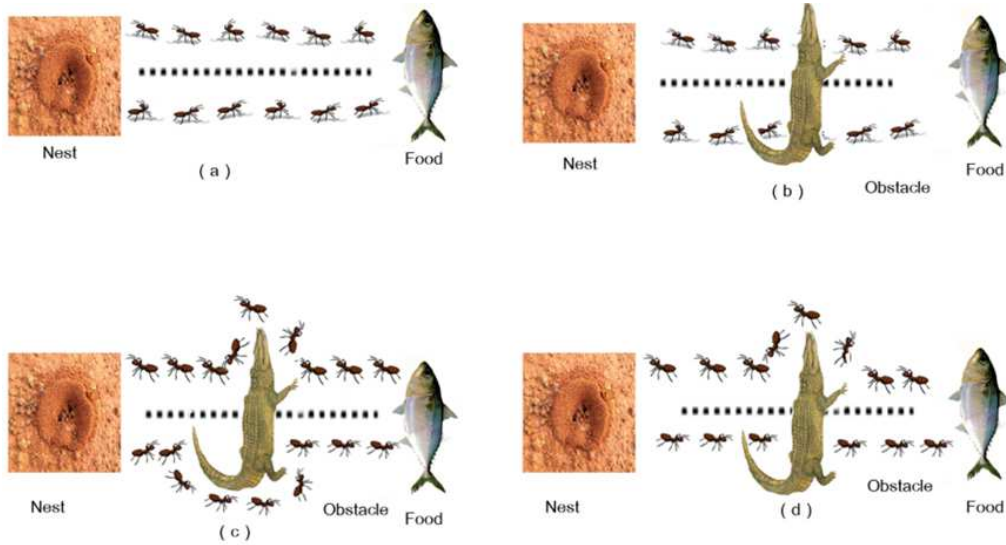


Fig. 3. Behavior of ants; (a) Real ants follows a path between nest and food source. (b) An obstacle appears on the path: Ants choose whether to turn left or right with equal probability. (c) Pheromone is deposited more quickly on the shorter path. (d) All ants have chosen the shorter path

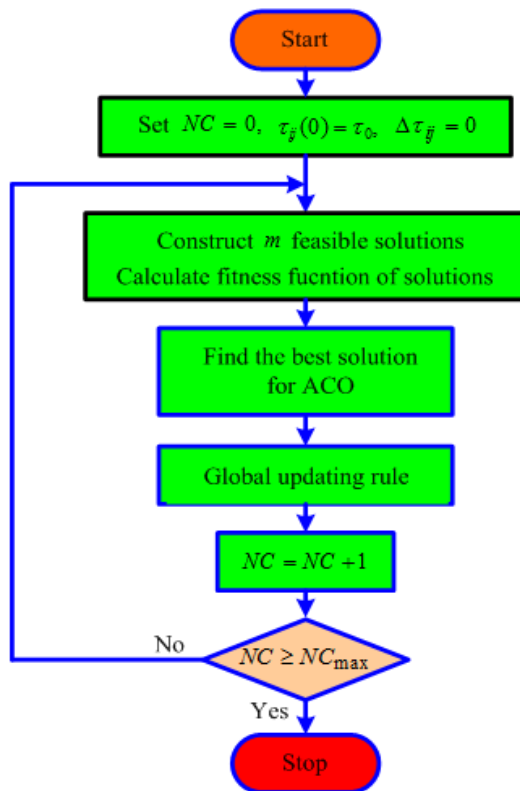


Fig. 4: Flow chart of conventional ACO algorithm

Global Updating Rule

During the solution construction, it is no guarantee that an ant will construct a feasible solution, which obeys the reliability constraint. The pheromone updating treats

the unfeasible solution. The amount of pheromone, deposited by ants, is set to a high value if the generated solution is feasible. On other hand, this value is set to a low value if it is infeasible. Therefore, this value depends on the solution quality. Infeasibility can be handled by assigning the penalty which proportion to the amount of reliability violations. In case of feasible solution, an additional penalty is introduced to improve its quality.

Following the above remarks, the trail intensity is updated as follows:

$$\tau_{ij}(new) = \rho \tau_{ij}(old) + \Delta \tau_{ij} \quad (8)$$

ρ is a coefficient such that $(1-\rho)$ represents the evaporation of trail and $\Delta \tau_{ij}$ is:

$$\Delta \tau_{ij} = \sum_{k=1}^m \Delta \tau_{ij}^k \quad (9)$$

where, m is the number of ants and $\Delta \tau_{ij}^k$ is given by:

$$\Delta \tau_{ij}^k = \begin{cases} Q \cdot \text{penalty}_k \cdot C_k & \text{if the } k^{\text{th}} \text{ ant chooses level } j \text{ for link } i \\ 0 & \text{otherwise} \end{cases} \quad (10)$$

where, Q is a positive number and penalty_k is defined as follows:

$$\text{penalty}_k = \left(\frac{C_k}{C^*} \right)^a \quad (11)$$

C_k is the cost obtained by the k^{th} ant, C^* is the best obtained solution. Parameter a represents the relative importance of penalties.

Experiment Results and Discussions

To assess the feasibility solution of the swarm intelligence techniques i.e., GA, PSO and ACO, three take load sizes problems (small, medium and large problems) are applied. All optimization methods (GA, PSO and ACO) were implemented in MATLAB® package and the simulation cases done on a Intel Core i5-430M, 2.26GHz laptop computer with 4 GB RAM under Windows 8.

Each studied systems was run 30 times with differential random initial solutions. In order to evaluate the performance of each technique, the best, worst, average and standard deviation of the generation costs and the average of computational time to get near optimum solution are used for evaluation.

Unfortunately, the number of initial solutions and the computational time for an iteration of these techniques are different. Therefore, the execution of search was done by the same iterations. This method is not suitable for comparison. Consequently; this work uses the time limit as the stopping criterion. The search processes of all techniques are executed by the same time period; therefore, the maximum iteration of each technique depends on the time limit. When the search satisfies the stopping criterion, the best, worst, average and standard deviation of the generation costs and the average of computational time to get near optimum solution are reported.

Case Studies

There are 3, 7 and 10 jobs of dyeing production process of a textile industry. These processes consist of 10 steps as shown in Table 1. That needs to find the starting time of each job. So, the number of the feasible solutions is 1.3824×10^4 , 4.5865×10^9 and 6.3403×10^{13} respectively.

Simulation Results

After performed 30 trials, the best solutions of three methods are given in Table 6-8. The results of the ACO method in comparison with those of GA and PSO in terms of maximum, average, minimum generation cost, the standard deviation and average computational time are provided. Clearly, the ACO method has always better solutions than other methods.

Comparison of Three Methods

Solution Quality

For three size production cost 3, 7 and 10 jobs production process for 10 steps, the best solutions of three methods are given in Table 6-8 after performed 30 trials. The results of the ACO method are compared with those obtained by GA and PSO in terms of maximum, average, minimum tariffs cost, the standard deviation and average computational time, as provided. Obviously, all methods have succeeded in finding the near optimum solution presented in with a high probability. In order to demonstrate the efficiency of the ACO method, the distribution outlines of the best solution of each trial are considered. Figure 5-7 shows the distribution outlines of the best solution of each trial in case of 3, 7 and 10 jobs for production process 10 steps. The Table 9 are result after load shifting 3, 7, 10 jobs comparative flat rate for 3, jobs more than 3 jobs TOU tariffs cost 29.306%; 7 jobs saving is 25.120% and 10 jobs to be saving 21.57%. Figure 7, 8 and 10 shows the distribution outlines of the best solution of each trial in case of 3, 7, 10 jobs for production process 10 steps. Almost all tariffs costs obtained by the ACO method are lower. This verifies that the ACO method has better quality of solution. Almost all tariffs costs obtained by the ACO method are lower. This verifies that the ACO method has better quality of solution.

Table 6. Best results obtained 10 steps for small jobs (3 jobs) production process system using GA, PSO, and ACO

Methods	Max cost (Baht)	Average cost (Baht)	Min cost (Baht)a	SD	CPU time (sec)	Get optimum
PSO	7,836.41	7,836.41	7,836.41	0.0000000000027751	1.892	100
GA	7,836.41	7,836.41	7,836.41	0.0000000000027751	1.382	100
ACO	7,836.41	7,836.41	7,836.41	0.0000000000027751	1.069	100

Table 7. Best results obtained 10 steps for medium jobs (7 jobs) production process system using GA, PSO, and ACO

Methods	Max cost (Baht)	Average cost (Baht)	Min cost (Baht)	SD	CPU time (sec)	Get optimum
PSO	18,950.20	18,321.20	18,066.20	272.30	96.666	33.33
GA	18,192.50	18,078.70	18,066.20	0.00213168	26.922	90.00
ACO	18,310	18,074.30	18,066.20	44.515	19.904	96.66

Table 8. Best results obtained 10 steps for large jobs (10 jobs) production process system using GA, PSO, and ACO

Methods	Max cost (Baht)	Average cost (Baht)	Min cost (Baht)	SD	CPU time (sec)	Get optimum
PSO	27,962.90	27,027.30	26,379.00	568.84	121.34	0
GA	26,717.00	26,268.00	26,054.00	0.00856645	302	0
ACO	26,232.40	26,035.10	25,912.50	0.00296387	0.83	16.666

Table 9. The Result for 3, 7 and 10 jobs of load-shifting technique for case study

Job process	Flat rate cost (Baht)	After shifting with TOU tariffs cost (Baht)	% Saving
3jobs	11,085	7,836.41	29.306
7jobs	24,127	18,066.20	25.120
10jobs	33,040	25,912.50	21.570

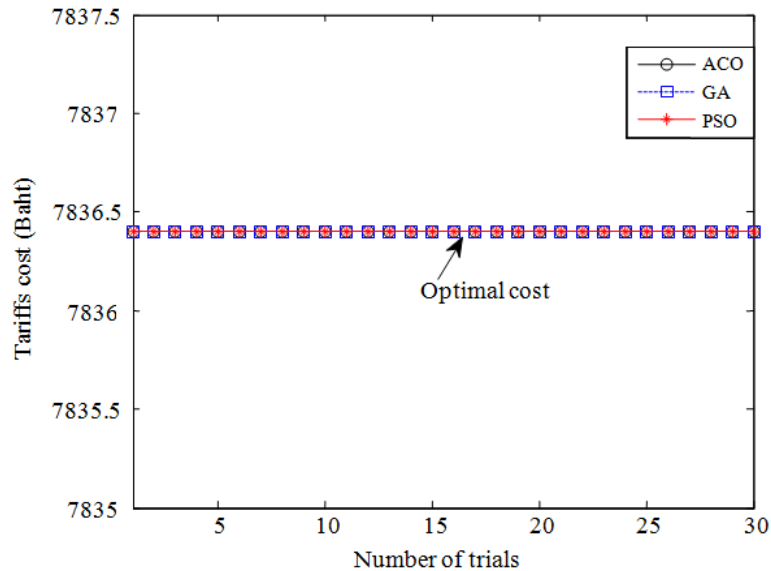


Fig. 5. Distribution of tariffs cost of three methods of 3 jobs for 10 step production process system

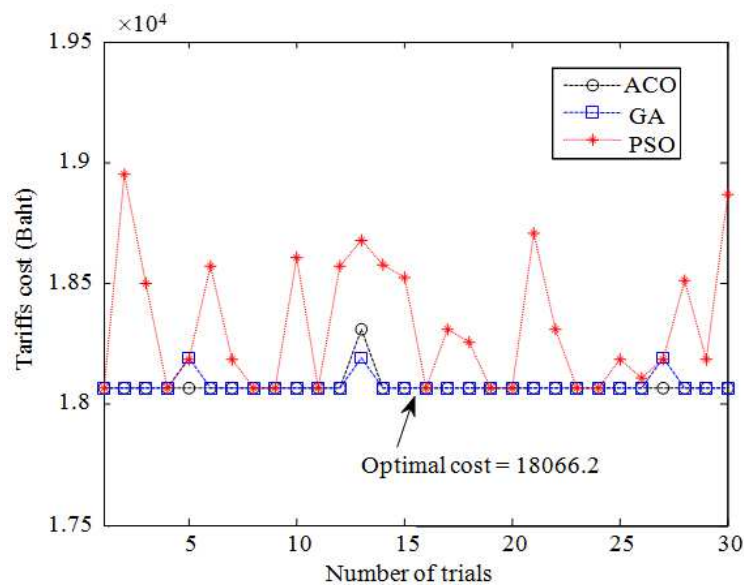


Fig. 6. Distribution of tariffs cost of three methods of 7 jobs of 10 steps production process system

Computation Efficiency

The convergent characteristics of the ACO compared with other methods for both case studies are shown in Fig. 8-10. Clearly, the ACO converges to the

optimum solution much faster than other methods. Furthermore, the comparisons of computation time of five methods for three studies system are already given in Table 6, 7 and 10. The ACO method has better quality of solution.

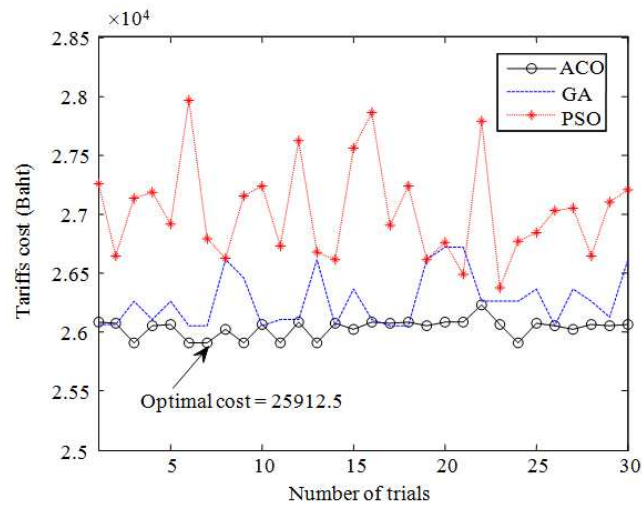


Fig. 7. Distribution of tariffs cost of three methods of 10 jobs for 10 step production process system

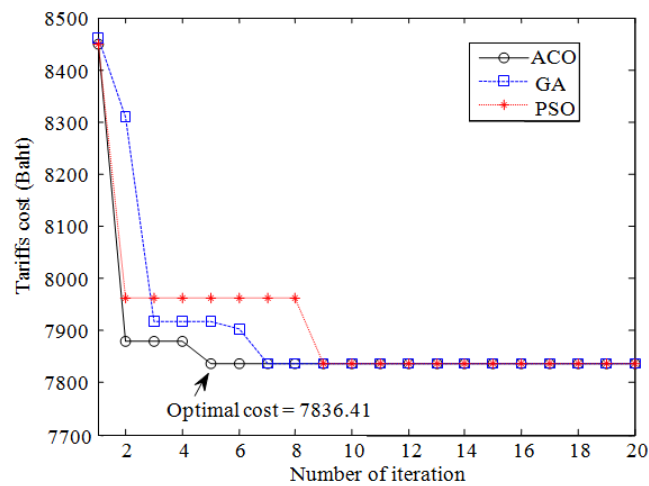


Fig. 8. Convergence curve three methods of 3 jobs for 10 steps production process system

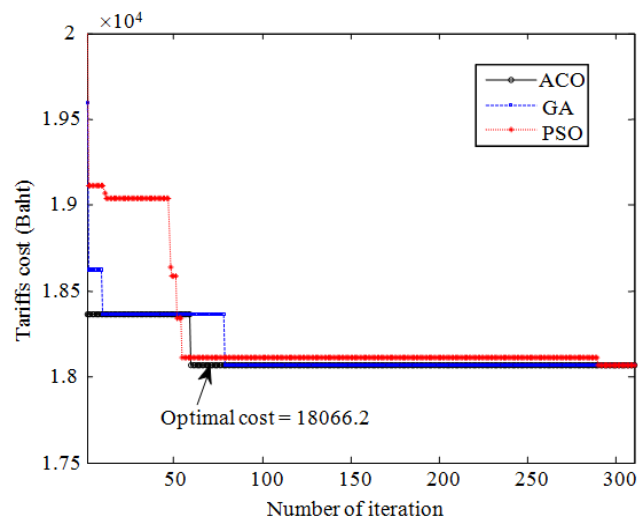


Fig. 9. Convergence curve three methods of 7 jobs for 10 steps production process system

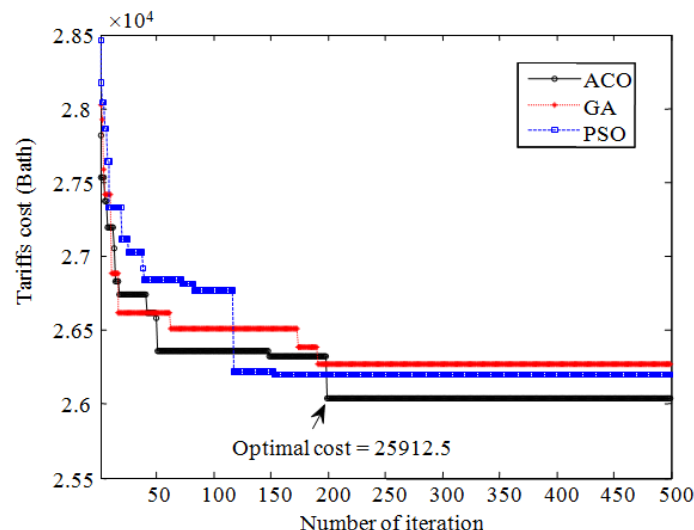


Fig. 10. Convergence curve three methods of 10 jobs for 10 steps production process system

Conclusion

In this study, the ACO algorithm has been proposed to solve the LS problem by taking the three size problem (small, medium and large scale) and load shifting effects into the case studies in case of Single Process Multiple Jobs (SPMJ) to minimize the total electricity cost under varying tariffs such as flat rate and Time of Use (TOU) consideration. Numerical testing and a comparative analysis show that the proposed ACO algorithm outperforms other methods i.e., GA and PSO in terms of high-quality solution, stable convergence characteristic and good computation efficiency.

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Author's Contributions

Authors equally contributed to this article.

Ethics

This article is original research and contains unpublished material. The corresponding author confirms

that all of the other authors have read and approved the manuscript and no principled issues concerned.

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