

Multi-matrix Real-coded Genetic Algorithm for Minimising Total Costs in Logistics Chain Network

Pupong Pongcharoen, Aphirak Khadwilard, and Anothai Klakankhai

Abstract—The importance of supply chain and logistics management has been widely recognised. Effective management of the supply chain can reduce costs and lead times and improve responsiveness to changing customer demands. This paper proposes a multi-matrix real-coded Generic Algorithm (MRGA) based optimisation tool that minimises total costs associated within supply chain logistics. According to finite capacity constraints of all parties within the chain, Genetic Algorithm (GA) often produces infeasible chromosomes during initialisation and evolution processes. In the proposed algorithm, chromosome initialisation procedure, crossover and mutation operations that always guarantee feasible solutions were embedded. The proposed algorithm was tested using three sizes of benchmarking dataset of logistic chain network, which are typical of those faced by most global manufacturing companies. A half fractional factorial design was carried out to investigate the influence of alternative crossover and mutation operators by varying GA parameters. The analysis of experimental results suggested that the quality of solutions obtained is sensitive to the ways in which the genetic parameters and operators are set.

Keywords—Genetic Algorithm, Logistics, Optimisation, Supply Chain.

I. INTRODUCTION

CUSTOMER satisfaction is one of the major issues for any downstream business that requires effective logistics. Effective logistics may be defined as the art of bringing the right amount of the right product to the right place at the right time with minimising costs related within and between all parties and usually refers to supply chain problems. A typical logistics chain commonly (see Fig. 1) involves a network of tiered suppliers producing raw materials, parts, components, subassemblies, assemblies and final products together with distribution centres/warehouses, wholesalers and retailers/customers.

In order to meet customers' demand, costs related to raw materials, production, holding, multi-stage transportation and fixed operation costs are arising in the logistics chain network.

Manuscript received October 15, 2007. This work was supported in part by the Faculty of Engineering, Naresuan University.

P. A. Pongcharoen is with the Faculty of Engineering, Naresuan University, Pitsanulok, Thailand (corresponding author to provide phone: + 66 55 261061 ext 4201; fax: + 66 55 261062; e-mail: pupongp@nu.ac.th and pupongp@yahoo.com).

A. Khadwilard is with the Faculty of Engineering, Rajamangala University of Technology Lanna, Tak, Thailand.

A. Klakankhai is with the Faculty of Engineering, Naresuan University, Pitsanulok, Thailand.

The design task is to minimise these costs, which can be mathematically formulated and solved using enumerative methods such as Integer Linear Programming [1] or stochastic search techniques (sometimes called meta-heuristics) such as Genetic Algorithm [2], [3]. However, GA proposed by [2] has not been based on matrix and unfortunately produced infeasible offspring, which is omitted from the iterative evolution process within the GA. The work in [3] ignored raw material, manufacturing and holding cost from the objective function and similarly proposed a repair process for rectifying infeasible chromosome.

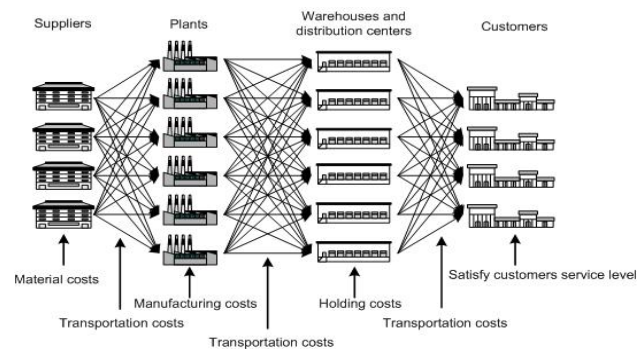


Fig. 1 Typical logistics chain network

Genetic Algorithm (GA) has several advantages; multiple directional searches, problem coding instead of decision variables and using stochastic transition rules [4], [5]. It has therefore been widely used to solve production and operation management (POM) problems such as supply chain and logistics [1], production scheduling [6], facility layout [7] and university course timetabling [8]. However, the GA applications on some POM problem areas such as transportation within logistics chain network [9], quality planning, short/long term forecasting and short-term capacity planning have rarely been found [10].

The flexibility of chromosome representation is one of the major advantage strategies within the genetic algorithm (GA). For example, a single row chromosome representation is normally used for solving sequencing or scheduling problems whilst a single matrix-based chromosome representation is required for a candidate solution of a single stage transportation problem. Sun et al. [11] have applied a single matrix-based GA for solving the unit commitment problem, which plays an important role in the economic operation of

power system. In their work, the repair mechanism is additionally embedded in the GA for dealing with the infeasible solutions generated. However, a multi-matrix based chromosome is required to represent a multiple stage transportation problem, which is usually occurred in a logistics chain network.

Genetic operations including crossover and mutation are the main stochastic search process within the GA. Crossover operation helps search strategy to explore the solution space whilst exploitation is conducted by the mutation mechanism. Fifteen crossover operations and eleven mutation techniques have been reviewed and investigated in literature [12]. However, the majority of those operations are suitable for single row chromosome and often produce infeasible offspring. In the present work, alternative crossover and mutation operators were proposed and their performance was investigated.

The objectives of this paper were to i) present the mathematical model for minimising total costs raised from raw material, manufacturing, holding inventory, transportations between parties and fixed operation costs; ii) describe a multi-matrix real-coded Genetic Algorithm (MRGA) that always guarantee feasible solutions obtained from both initialisation and evolution processes and iii) present the computational experiments for investigating genetic parameters and operators using three sizes of dataset.

The remaining of the paper is organised as follows. Section 2 describes the logistics chain network and its related costs including mathematical model. Matrix based Genetic Algorithm that was developed for minimising total costs arising in logistics networks are presented in section 3. Section 4 briefly describes the case study and the data used. Section 5 presents the experimental design and analysis followed by conclusions in section 6.

II. LOGISTICS CHAIN NETWORK (LCN) PROBLEM

Typical problem arising in a logistic chain network is involved in determining the choice of available facilities (such as plants and warehouses) to be opened and in designing the transportation routing between parties (from suppliers via plants and warehouses/distribution centres to customers) in order to meet customers' demand with minimum cost [13], [14]. The problem is usually constrained by the finite capacity limitation on each suppliers, plants and warehouses. Due to the transportation network design, the LCN problem can therefore be referred to a multiple stages capacitated transportation/ allocation problem known to be NP-hard, which can alternatively be solved using GA [5].

Considering a general steady stage supply chain network, there are a number of suppliers, plants, distribution centres/warehouses and its capacity limitation aiming to satisfy customer demand given by the contract. For example in capital goods companies, most of main products are high value and are demanded in low volume [15]. The desired amount of goods are manufactured and delivered based on JIT

philosophy. The objective function (1) reflects a total costs to be minimised. The equation composed of five parts. The first three parts considers the raw materials, manufacturing, holding costs and its transportation between parties, respectively. The rest two parts take into account the fixed operating cost for plants and warehouses.

Notation:

- i denotes supplier i^{th} in the set of suppliers (I)
- j denotes plant j^{th} in the set of plants (J)
- k denotes warehouse k^{th} in the set of DC (K)
- l denotes customer l^{th} in the set of customers (L)
- a_{ij} is transportation cost per unit of raw material flow from supplier i^{th} to plant j^{th} .
- b_{jk} is carrying cost per unit of finished goods moved from plant j^{th} to warehouse k^{th} .
- c_{kl} is moving cost per unit of goods deliver from warehouse k^{th} to customer l^{th} .
- x_{ij} is the amount of raw material transferred from supplier i^{th} to plant j^{th} .
- y_{jk} is the amount of finished goods moved from plant j^{th} to warehouse k^{th} .
- z_{kl} is the amount of finished goods delivered from warehouse k^{th} to customer l^{th} .
- S_i is the upper limit of supplier i^{th} can supply.
- P_j is the production capacity of plant j^{th} .
- W_k is the storage limit of warehouse k^{th} .
- C_l is the demand of customer l^{th} .
- f_j is the fixed cost for operating at plant j^{th} .
- f_k is the fixed cost for operating at warehouse k^{th} .
- $t_j = 1$ if production takes place at plant j^{th} , otherwise 0
- $t_k = 1$ if warehouse k^{th} is used, otherwise 0

$$\text{Minimise } \sum_{i=1}^I \sum_{j=1}^J (a_{ij} + r_i) x_{ij} + \sum_{j=1}^J \sum_{k=1}^K (b_{jk} + m_j) y_{jk} + \sum_{k=1}^K \sum_{l=1}^L (c_{kl} + h_k) z_{kl} + \sum_{j=1}^J f_j t_j + \sum_{k=1}^K f_k t_k \quad (1)$$

$$\sum_{j=1}^J x_{ij} \leq S_i, \forall i, j \quad (2)$$

$$\sum_{k=1}^K y_{jk} \leq P_j, \forall j, k \quad (3)$$

$$\sum_{l=1}^L z_{kl} \leq W_k, \forall k, l \quad (4)$$

$$\sum_{k=1}^K z_{kl} = C_l, \forall k, l \quad (5)$$

$$\sum_{i=1}^I x_{ij} \leq P_j t_j, \forall i, j \quad (6)$$

$$\sum_{j=1}^J y_{jk} \leq W_k t_k, \forall j, k \quad (7)$$

$$\sum_{i=1}^I \sum_{j=1}^J x_{ij} = \sum_{j=1}^J \sum_{k=1}^K y_{jk} = \sum_{k=1}^K \sum_{l=1}^L z_{kl} = \sum_{l=1}^L C_l, \forall i, j, k, l \quad (8)$$

$$x_{ij}, y_{jk}, z_{kl} \geq 0, \forall i, j, k, l \quad (9)$$

$$t_j, t_k = \{0, 1\}, \forall j, k \quad (10)$$

Constraint (2) (3) (4) and (5) represent the capacity limitations of the suppliers, plants, warehouse/distribution centres and customers, respectively. Constraint (6) ensures that raw materials are delivered to only operating plants; likewise, constraint (7) for only operating warehouses. Constraint (8) ensures that the same amount of items is transported in each stage and also meets customers' demand. In the case of unbalanced supply and demand, a dummy supplier or customer may be introduced. Constraint (9) ensures that transportation variables are greater or equal to zero whilst binary decision variables are specified in the last constraint.

III. MULTI-MATRIX REAL-CODED GENETIC ALGORITHM (MRGA)

Genetic Algorithm (GA) is stochastic search technique based upon the mechanics of natural selection [4], [5]. The basic idea came from an analogy with biological evolution, in which the fitness of individual determines its ability to survive and reproduce. In this work, multi-matrix real-coded Genetic Algorithm (MRGA) was developed for minimising total costs arising in the logistics chain network. The initialisation process and genetic operations that always produce feasible chromosome were proposed. The general process of the MRGA that mainly included chromosome representation and initialisation, genetic operations and chromosome evaluation and selection are described in followings sub-sections.

A. Chromosome Representation and Initialisation

Multiple matrix based chromosome representation is used to represent the multi-stage transportation network between parties in the logistics chain network (LCN). For example, three stages LCN problem (shown in Figure 1) consists of a set of suppliers (I), plants (J), warehouses/distribution centres (K) and customers (L). This gives rise three-stage transportation matrices (M) of suppliers to plants (M_{IJ}), plants to warehouses (M_{JK}) and warehouses to customers (M_{KL}). Each matrix is called sub-chromosome. Fig. 2 shows multiple matrix based chromosome representation.

$$M_{IJ}M_{JK}M_{KL} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1J} \\ x_{21} & x_{22} & \dots & x_{2J} \\ \vdots & \vdots & \dots & \vdots \\ x_{I1} & x_{I2} & \dots & x_{IJ} \end{bmatrix} \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1K} \\ x_{21} & x_{22} & \dots & x_{2K} \\ \vdots & \vdots & \dots & \vdots \\ x_{J1} & x_{J2} & \dots & x_{JK} \end{bmatrix} \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1L} \\ x_{21} & x_{22} & \dots & x_{2L} \\ \vdots & \vdots & \dots & \vdots \\ x_{K1} & x_{K2} & \dots & x_{KL} \end{bmatrix}$$

Fig. 2 Multiple matrix real-coded based chromosome representation

In the present work, the chromosome initialisation process, in which all chromosomes generated were ensured to be feasible solutions, was proposed. The process sequentially considered matrix by matrix based on the finite capacity limitations arising from all parties. The process of sub-chromosome initialisation was divided into two parts; creating sequence number (s/n) and assigning the values for each

element (x_{ij}) in the matrix size of $I \times J$ for instance.

Part I: Creating s/n for all elements (x_{ij}) in the matrix (M_{IJ}).

Step 1 Generate random value (v_{ij}) between 0 to 1 for all elements (x_{ij}) in M_{IJ} .

Step 2 Find an ascending sequence started from 1 to $I \times J$ for all x_{ij} by considering the value of v_{ij} . The x_{ij} with smallest value of v_{ij} will be assigned a sequence number (s/n) = 1 whilst s/n of $I \times J$ will be assigned to the x_{ij} , which has the largest value of v_{ij} .

Part II: Assigning the values of x_{ij} in the matrix (M_{IJ}).

Step 1 Set the values of all x_{ij} initially equal to zero.

Step 2 Start from the element x_{ij} with $s/n = 1$, then repeat the following steps until $s/n = I \times J$.

Step 3 Compare the capacity constraints of row i^{th} (r_i) and column j^{th} (c_j). If $r_i \leq c_j$, then $x_{ij} = x_{ij} + r_i$; $c_j = c_j - r_i$; and set $r_i = 0$. Otherwise, $x_{ij} = x_{ij} + c_j$; $r_i = r_i - c_j$; and set $c_j = 0$.

Step 4 Then increasing the sequence number; $s/n = s/n + 1$.

B. Genetic Operations: Crossover and Mutation

Several crossover and mutation operations have been intensively reviewed and statistically investigated in literature [12]. Unfortunately, most of them are not matrix based operations and do not guarantee feasible offspring regarding to the constraints considered. There are three ways to deal with infeasible chromosomes: i) discarding them; ii) applying a high penalty in the fitness function so that they are unlikely to survive; or iii) repairing them [16]. Avoiding infeasible solutions may be benefit on decreasing the iterative computational effort. In this present work, two matrix based crossover and mutation operations that always guarantee feasible offspring were developed and described as follows;

Crossover type I was based on the concept of one point crossover by performing between matrices. For example, two chromosomes were randomly selected as parents (see Fig. 3), each of which consisting of three sub-chromosomes (matrices); M_1 , M_2 and M_3 . A cutting point was randomly generated between matrices and then performing a swap.

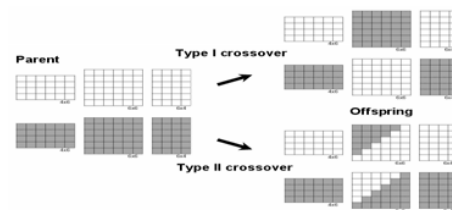


Fig. 3 Type I and II of crossover operations

Crossover type II was aimed to perform crossover operation on a randomly selected matrix (see Fig. 3). The similar concept described in the chromosome initialisation process was adopted as follows;

Step 1 Randomly select a point regarding to the length of the sub-chromosome.

Step 2 Perform one point crossover operation on the

sequence number (s/n) created during chromosome initialisation for each element (x_{ij}) in the corresponding matrix (M_{ixj}). This step is therefore reproducing two offspring that have new sequence number for each element (x_{ij}) in the matrix.

- Step 3 Follow the process of assigning the values of x_{ij} as described in part 2 of the chromosome initialisation procedure for all offspring obtained from step 2.

Procedure: Mutation type I.

- Step 1 Randomly select a sub-chromosomes in a parent.
- Step 2 Randomly choose a gene within the selected sub-chromosome and then perform a swap of sequence number (s/n) between the chosen gene with the successive gene. This step is therefore reproducing an offspring that have new sequence number for each element (x_{ij}) in the matrix.
- Step 3 Perform the process of assigning the values of x_{ij} in the matrix described in part 2 of chromosome initialisation procedure for the offspring obtained from step 2.

Procedure: Mutation type II.

- Step 1 Randomly select a sub-chromosomes in a parent.
- Step 2 Perform part 1 and 2 described in the chromosome initialisation procedure for the offspring obtained from step 2. This means that a brand new matrix replaces the chosen one.

C. Chromosome Evaluation and Selection

Chromosome evaluation is usually applied to measure the performance (fitness value) of a candidate solution (individual) by determining an objective (fitness) function. The higher fitness value of individual is, the higher its chances to be selected onto the next generation. In this present work, the total costs arising within and between parties in the logistics chain network described in section 2 was used as fitness function. The famous chromosome selection called roulette wheel was then applied for randomly choosing the same amount of individual onto the next generation. The MRGA process was repeated until the termination criteria were satisfied.

IV. CASE STUDY

The logistic chain network (LCN) problem is to determine the choice of available facilities (plants and warehouses) to be opened and to design the transportation routing between parties, each of which has finite resource capacity, in order to meet customers' demand with minimum cost. In this present work, three problem sizes (see Table I) for designing the LCN were proposed in order to test the model developed. For example, the large problem involved eight suppliers, sixteen plants, sixteen warehouses and eight retailers. To solve the problem using liner programming (LP), it required 512 integer and 32 binary variables based on 625 constraints. The best

solutions for these benchmarking problems were initially identified by LP method using a software package. Due to the limited (student) version of the software package used, only total costs for small and medium size problems were found at 87,500 and 187,800 baht, respectively. These results were then used for benchmarking the performance of the model developed in the next section.

TABLE I
CHARACTERISTICS OF THE BENCHMARKING PROBLEMS

Characteristics	Problem sizes		
	Small	Medium	Large
Number of suppliers	4	8	8
Number of plants	6	10	16
Number of warehouses	6	10	16
Number of retailers	4	8	8
Total number of integer variables	84	260	512
Total number of binary variables	12	20	32
Number of constraints	129	337	625

V. EXPERIMENTAL DESIGN AND ANALYSIS

A two-step sequential experiment was adopted in this present work. The first experiment (Experiment A) was aimed to investigate the influence of alternative crossover and mutation operators by varying GA parameters. Another experiment (Experiment B) was intended to compare the performance of the developed model with the benchmarking results obtained from enumerative method called linear programming.

A. Experiment A

Half fractional factorial experimental design [17] with ten replications was carried out to solve each problem size. The experimental factors and its values considered are shown in Table II. The first factor was the combination of population size and number of generations (P/G), which determines the total chromosomes to be investigated. This factor had an influence on the exploration process of seeking (generated) results in the solution space and also delaying the execution time of the computational run. In this present work, total amount of chromosomes generated was fixed at 1,000 according to preliminary test runs. The values setting of the probabilities of crossover (P_c) and mutation (P_m) was based on the suggestions in previous research [18], [19]. The remaining two factors were the crossover and mutation operators (COP and MOP) described in the aforementioned section. These alternative operators proposed in this work were matrix based operations and always guarantee to produce feasible offspring.

TABLE II
EXPERIMENTAL FACTORS AND ITS LEVEL

Factors	Levels (coded)	
	Low (-)	High (+)
Population/Generation (P/G)	50/20	20/50
Probability of crossover (P_c)	0.6	0.9
Probability of mutation (P_m)	0.1	0.5
Crossover operation (COP)	Type I	Type II
Mutation operation (MOP)	Type I	Type II

The experiments for each problem size were carried out on a notebook computer with AMD Athlon 1400+ and 128 MB SDRAM. The experimental results obtained from 160 (24x10) runs were analysed using a general linear form of analysis of variance and main effect plots. The significant factors indicated using underline and its appropriate setting based on each problem size is summarised in Table III. It can be seen that all factors with an exception of Pc were statistically significant with 95% confidence interval. The best settings of some factors (P/G, Pm and COP) were in agreement for all problem size but the remaining factors were not. These findings of parameters' setting were used in the sequential experiment presented in the next section.

TABLE III
SIGNIFICANT FACTORS AND ITS LEVEL ON EACH PROBLEM SIZE

Problem sizes	GA parameters				
	P/G	Pc	Pm	COP	MOP
Small	<u>Low</u>	High	<u>High</u>	<u>Low</u>	High
Medium	<u>Low</u>	Low	High	Low	Low
Large	<u>Low</u>	High	High	<u>Low</u>	<u>Low</u>

B. Experiment B

This experiment was aimed to compare the results obtained from the Multi-matrix Real-coded Genetic Algorithm (MRGA) with the benchmarking results obtained from linear programming (see Table IV). It was found that the total costs obtained from the MRGA were very close to the optimum solutions identified by linear programming using a software package. Due to the limited (student) version of the software used, only optimum solutions of small and medium problem were provided. The large problem required 544 variables and 625 constraints, which exceed the limitation of the version.

TABLE IV
PERFORMANCE COMPARISON ON EACH PROBLEM SIZE

Problem sizes	Total cost (Baht)		% near optimum
	MRGA	Optimum	
Small	88,150	87,500	0.74%
Medium	199,000	187,800	5.96%
Large	674,300	-	-

VI. CONCLUSION

This paper proposed the Multi-matrix Real-coded Generic Algorithm (MRGA) based optimisation tool that minimises total costs associated within supply chain logistics. Since the simple GA often produces infeasible chromosomes during initialisation and evolution processes due to finite capacity constraints of all parties within the chain, an alternative matrix based chromosome initialisation procedure, crossover and mutation operations that always guarantee feasible solutions were therefore proposed in this paper. The proposed algorithm was tested using three sizes of benchmarking dataset of logistic chain network, which are typical of those faced by

most global manufacturing companies. A sequential experiment was systematically carried out to investigate the influence of alternative crossover and mutation operators by varying GA parameters and to identify how close the MRGA can find the near optimum solutions. The analysis of experimental results suggested that the quality of solutions obtained is sensitive to the ways in which the genetic parameters and operators are set. It was also found that the best results obtained from the MRGA were less than 6 percent deviated from the optimum solutions.

REFERENCES

- [1] H. Gunnarsson, M. Ronnqvist, and J. T. Lundgren, "Supply chain modelling of forest fuel," *Eur. J. Oper. Res.*, vol. 158, no. 1, pp. 103-123, 2004.
- [2] R.Z. Farahani, and M. Elahipanah, "A genetic algorithm to optimize the total cost and service level for just-in-time distribution in a supply chain," *Int. J. Prod. Econ.*, to be published.
- [3] A. Syarif, Y. Yun, and M. Gen, "Study on multi-stage logistic chain network: a spanning tree-based genetic algorithm approach," *Comp. Ind. Eng.*, vol. 43, no. 1-2, pp. 299-314, 2002.
- [4] D. E. Goldberg, *Genetic Algorithms in Search, Optimisation and Machine Learning*. Massachusetts, Addison-Wesley, 1989.
- [5] M. Gen, and R. Cheng, *Genetic Algorithms and Engineering Design*. New York, John Wiley and Sons, 1997.
- [6] P. Pongcharoen, C. Hicks, and P. M. Braidon, "The development of genetic algorithms for the finite capacity scheduling of complex products, with multiple levels of product structure," *Eur. J. Oper. Res.*, vol. 152, no. 1, pp. 215-225, 2004.
- [7] C. Hicks, "A Genetic Algorithm tool for optimising cellular or functional layouts in the capital goods industry," *Int. J. Prod. Econ.*, vol. 104, no. 2, pp. 598-614, 2006.
- [8] P. Pongcharoen, W. Promtet, P. Yenradee, and C. Hicks, "Stochastic optimisation timetabling tool for university course scheduling," *Int. J. Prod. Econ.*, to be published.
- [9] H. Aytug, M. Knouja, and F. E. Vergara, "Use of genetic algorithms to solve production and operations management problems: a review," *Int. J. Prod. Res.*, vol. 41, no. 17, pp. 3955-4009, 2003.
- [10] S. S. Chaudhry, and W. Luo, "Application of genetic algorithms in production and operation management: a review," *Int. J. Prod. Res.*, vol. 43, no. 19, pp. 4083-4101, 2005.
- [11] L. Sun, Y. Zhang, and C. Jiang, "A matrix real-coded genetic algorithm to the unit commitment problem," *Elec. Pow. Syst. Res.*, vol. 76, no. 9-10, pp. 716-728, 2006.
- [12] P. Pongcharoen, D. J. Stewardson, C. Hicks, and P. M. Braidon, "Applying designed experiments to optimize the performance of genetic algorithms used for scheduling complex products in the capital goods industry," *J. Appl. Stat.*, vol. 28, no. 3-4, pp. 441-455, 2001.
- [13] D. Simchi-Levi, P. Kaminsky, and E. Simchi-Levi, *Designing and managing the supply chain: concepts, strategies and case studies*. McGraw-Hill, 2003.
- [14] S. Chopra, and P. Meindl, *Supply chain management: strategy, planning and operations*. Prentice Hall, 2004.
- [15] C. Hicks, T. McGovern, and C. F. Earl, "A typology of UK engineer-to-order companies," *Int. J. Logis. Res. and Appl.*, vol. 4, no. 1, pp. 43-56, 2001.
- [16] C. Blum, and A. Roli, "Metaheuristics in combinatorial optimization: Overview and conceptual comparison," *ACM Comp. Surv.*, vol. 35, no. 3, pp. 268-308, 2003.
- [17] D. C. Montgomery, *Design and analysis of experiments*. NY: John Wiley and Sons, 2001.
- [18] P. Pongcharoen, C. Hicks, P. M. Braidon, and D.J. Stewardson, "Determining optimum genetic algorithm parameters for scheduling the manufacturing and assembly of complex products," *Int. J. Prod. Econ.*, vol. 78, no. 3, pp. 311-322, 2002.
- [19] P. Pongcharoen, W. Chainate, and P. Thapatsuan, "Exploration of genetic parameters and operators through travelling salesman problem," *ScienceAsia*, vol. 33, no. 2, pp. 215-222, 2007.

Pupong Pongcharoen is an Assistant Professor in Industrial Engineering, Faculty of Engineering, Naresuan University, Phitsanulok, Thailand. He graduated a bachelor degree in industrial engineering from Chiang Mai University, Chiang Mai, Thailand. He graduated a master degree from the Department of Industrial System Engineering and Management, School of Advanced Technology, the Asian Institute of Technology. He received a Ph.D. from the Department of Materials, Mechanical and Manufacturing Engineering, Faculty of Engineering at the University of Newcastle upon Tyne, Newcastle upon Tyne, United Kingdom.

He has been appointed as a lecturer in Industrial Engineering Department, Naresuan University since 1994. His teaching and research interests include manufacturing planning and scheduling especially in engineer/make-to-order strategy, computer simulation, supply chain and logistics management, metaheuristics, applied statistics and operations research on industrial systems. His has had several publications in international journals such as Journal of Applied Statistics, International Journal of Production Economics, International Journal of Technology Management, European Journal of Operations Research and Scienceasia.

Dr. Pongcharoen has been invited to be a reviewer of international journals such as European Journal of Operations Research, International Journal of Production Economic, International Journal of Production Research, International Journal of Manufacturing Technology and Management, and International Journal of Industrial Engineering and Management Systems.

Aphirak Khadwilard is a lecturer in the Faculty of Engineering, Rajamangala University of Technology Lanna, Tak, Thailand. He graduated a bachelor degree in mechanical engineering from Rajamangala Institute of Technology, Bangkok, Thailand. He graduated a master degree from the Department of Industrial Engineering, Faculty of Engineering, Naresuan University, Phitsanulok, Thailand.

He has been appointed as a lecturer in the Faculty of Engineering, Rajamangala University of Technology Lanna since 1995. His teaching and research interests include automatic control, mechanical vibration and application of metaheuristics in engineering design.

Anothai Klakankhai is currently a staff in the Faculty of Engineering, Naresuan University, Phitsanulok, Thailand, from which he graduated bachelor and master degrees in industrial engineering.

His research interests include supply chain and logistics management and metaheuristics applied on industrial systems.