Modified Differential Evolution Algorithm for Solving Economic Crop Planning in the Northeastern Region of Thailand

Phajongjit Pijitbanjong[1st]
Faculty of Industrial Technology
Songkhla Rajabhat University
Songkhla, Thailand
phajongjit@gmail.com

Udompong Ketsripongsa[2nd]
Faculty of Industrial Technology
Buriram Rajabhat University
Buriram, Thailand
udompong.jo@gmail.com

Rapeepan Pitakaso[3rd]
Faculty of Engineering
Ubon Ratchathani University
Ubon Ratchathani, Thailand
rapeepan.p@ubu.ac.th

Paroon Mayachearw[4st]
Faculty of Engineering
Princess of Naradhiwas University
Narathiwat,Thailand
paroon27@hotmail.com

Chaiya Chomchalao[5th]
Faculty of Engineering
Nakhon Phanom University
Nakhon Phanom, Thailand
chaiya_npu@hotmail.com

***Abstract*—The purpose of this research was to planning to cultivate economic crops by developing mathematical models and algorithms to solve the problem of planning the selection to find appropriate areas for cultivate economic crops. To consider the economic value for farmers to receive the most profit by using sub-district level information in 8 provinces in the northeastern region of Thailand. The 3 types of economic crops are rice, cassava and sugarcane. This research developed a mathematical model and solved the problem by 3 methods i.e. the LINGO V.11 software, the Difference Evolution algorithm (DE) and Modified Difference Evolution algorithm using the Random best algorithm method (MDE-R). The results from the problem instances categorized into 3 groups showed that testing with small size instances using the LINGO V.11 software and the DE method both gave the same answer but the DE method took less time. When testing with medium size, large size, and case study instances by using the DE and MDE-R methods was found that the MDE-R method gave better answers than DE method at the equal time. The optimization of the highest profit was 12,760,520 baht per cycle.**

Keywords—differential evolution algorithm, modified differential evolution algorithm, crop planning

1. Introduction

Thailand's current economic crops such as rice, cassava, sugarcane and other plants are considered to be important to the country's economic growth due to generate revenue for the country. When the demand and supply of crop products is inconsistent, many problems rise for instant, the falling price of products, high production costs, imbalance between supply and demand, inadequate agricultural central markets in each area, long distance of transporting agricultural products from the cultivated area to the purchasing point in some remote areas etc. Therefore, it is necessary to consider the factors that affect the cultivation plan, e.g. finding the suitable area for each type of crop, the location of plants and central market, and transportation products etc. in order to achieve the maximum profit.

In Thailand, essential economic crops are cultivated in the northeastern region [1], where occupied by 63,846,932 rai. The area is divided into rice cultivation for 42,751,210 rai, field crops such as cassava and sugarcane for 11,941,028 rai and others for 9,154,694 rai. There are many factors involved the cultivation, such as the type of cultivated land, rate of return, weather conditions, and other factors that affect cultivation, such as rainfall, weather, floods, storms and other natural disasters, including some plants that require seasonal cultivation, such as rice, that can be planted for 2-3 times per year. Some species can be grown only once in cultivated areas such as sugarcane and cassava. Therefore, it is necessary to develop the database to support decision making on cultivate economic crops of farmers in the northeastern region of Thailand. It is also possible to be applied for production planning and product evaluation in advance in order to reduce the risk, problems and failures that occur to farmers in the future.

2. Literature Review

This study, therefore, did planning of growing rice, cassava and sugarcane in the high yielding and high price areas, also considered the locations of the plants that affected transportation cost in order to give the highest profit of the system. This kind of problem is considered NP-hard problem difficult to solve by Exact Method due to very long time consumed. The researcher then applied the Heuristic approach to solve such problems to reduce the time, to find the solution, and the quality of the answer that was acceptable. Qin and Suganthan [2] had developed the solution methods called Self-Adaptive Differential Evolution algorithm Numerical Optimization (SADE) based on the problem-solving principle of Differential Evolution algorithm by adjusting controlling factor (F) and crossover rate (CR) by pointing out that F and CR values were not needed to be determined in advance during the evolution. The parameters were gradually adjusted according to learning experience. The SADE test resulting to find the working efficiency of 25 standard sets by using real parameters was found to give satisfying values. From such good efficiency of DE, Chakraborty et al. [3] invented the new method of DE mutation by modeling 2 types of DE to test the 3 factors of mutant. The results showed statistical significance that this new mutant method provided better significance than the old 3-factor methods by using 6 test functions to measure efficiency such as quality problem solving method, time used to solve problem, frequency in solving problem and size of problem. Josiah and Fred [4] used evolution DE algorithms for solving crop growing problem under several objectives for maximized profit of water planning and crop yield. Similarly, Zou et al. [5] applied evolution DE algorithms to improve parameters of 2 major parts as factor size and Crossover Rate (CR) value by using the method called Improved Differential Evolution (IDE) by allowing Scale Factor to be adjustable and CR value to be changed step by step. The examples of problems were compared with the DE algorithms i.e. Opposition-based Differential Evolution (ODE) and Adaptive Differential Evolution with Optional External Archive (JADE) revealing that the improved IDE provided better answers than the two methods in term of cost reduction and efficiency. This research problem was complicated with many variables to be solved and probably consumed a lot of time to solve by computer software as work done by Pitakaso and Thongdee [6] using software to solve larger size problem. The result obtained could not confirm how long it needed to solve problem at each period of solving and showed status of possibility of receiving answers and was under all conditions in designing mathematical model and in other corners of research that could reduce some complicated stages of solving problem but obtaining good result and spending less time in finding answer than using software by Heuristic and Meta Heuristic method such as work done by Thongdee and Pitakaso [7] that compared solving problem efficiency between LingoV.11 software and algorithm development by modified differential evolution to measure of answer. The result obtained was able to reduce time finding problem up to 99% than Lingo V.11 software. Su et al. [8] proposed the method of assigning resource in case of urgent natural disasters that simultaneously occurred with the objective of reducing loss of lives and of economic aspect by DE method by building scheme as two dimensional integer vector of encoding. Each row represented rescue unit and each column represented occurring event. By considering of solving problem with this method, this is done together in response of time and cost aspects of urgent case resource. The problem was solved with more efficient than the older method. Sethanan and Pitakaso [9] proposed modified DE algorithm for solving general assignment by using the 3 methods of Local Search technique to improve better answers. These 3 methods have been extended to 7 methods. In addition, efficiency of each problem solving methods were measured to select the best method for comparing with BEE algorithm and Tabu algorithm in the experiment sample set of Gapa-Gape. The result showed that DE-SK method gave better answer than the other methods. Furthermore, many researches employed DE for solving for instant, Dechampai et al. [10] using DE algorithm for the capacitated VRP with Flexibility for mixing pickup and delivery services and the maximum duration route in poultry industry.

Literature review of work assignment and suitable location search and work allocation had been found that Differential Evolution algorithm [12-15] had good efficiency and with shorter time spend to find the optimal solution. The research then employed DE principle for cultivate crop planning and for location search of rice, cassava and sugarcane plants by economic considering in order to obtain maximum profit and DE method had been improved to find the answer with more efficiency.

3. Mathematical Model for Crop Planning

The mathematical model for the economic crop planning [12] was as follows:

3.1 Indices

- i stands for crop type (1=rice, 2=cassava, 3=sugarcane)
- j stands for planting area (j = 1, 2,.., 1,293)
- K stands for plant ($K = 1 \ldots K^i$, when K^1 = rice, K^2 = cassava , K^3 = sugarcane)

3.2 Parameters

- P_{ij} stands for crop price i planted by farmer j (Baht/Kilogram)
- C^1_{ij} stands for cost of planting i planted by farmer j (Baht/Rai)
- B_{ij} stands for rate of crop yield i planted by farmer j (Ton/Rai)
- A_j stands for planting area in each sub-district (Rai)
- D_{jk} stands for distance from planting area j to plant k (kilometer)
- C^2_i stands for transportation costs of each crop k (Baht/Kilometer)
- C_K stands for purchasing capacity of plant (Ton)
- C^3_{ij} stands for cost of crop cultivation i planted by farmer j (Baht/Rai)
- V_j stands for transportation capacity (Ton)
- M stands for maximum production capacity

3.3 Decision Variables

$$X_{ijk} = \begin{cases} 1 = \text{if there is transportation i from farmer j to plant k} \\ 0 = \text{other cases} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 = \text{if there is assign to plant crop i by farmer j} \\ 0 = \text{other cases} \end{cases}$$

- H_{ijk} = Quantity which plant k is given from crop i from farmer j
- T^1_{ij} = Number of transport cycles must be integer (Round)
- T^2_{ij} = Number of crop transportation i by farmer j (Round)

3.4 Mathematical Model

The researchers designed and developed the mathematical model by considering the highest profit for farmers. The related factors were considered consists of crop price, cost of each crop cultivation, yield rate of each crop, planning area in each sub-district, transportation distance from planning area to plant, cost of each crop transportation, amount of each crop transportation, and cost of cultivation as follows:

3.5 Objective Function

Maximize Z =

$$\sum_{i=1}^{I}\sum_{j=1}^{J}(P_{ij} - C^1{}_{ij})Y_{ij}B_{ij}A_j - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}X_{ijk}D_{jk}C^2{}_iT^2{}_{ij} - \sum_{i=1}^{I}\sum_{j=1}^{J}Y_{ij}C^3{}_{ij} \quad (1)$$

3.6 Constraints

$$\sum_{i=1}^{I} Y_{ij} = 1 \quad , \forall_{j \in J} \tag{2}$$

$$\sum_{j=1}^{J} Y_{ij} \geq 1 \quad , \forall_{i \in I} \tag{3}$$

$$\sum_{K \in K^i} H_{ijk} = Y_{ij} . B_{ij} . A_j \quad , \forall_{i \in I} \ \forall_{j \in J} \tag{4}$$

$$H_{ijk} \leq M . X_{ijk} \quad , \forall_{i \in I} \ \forall_{j \in J} \ \forall_{k \in K} \tag{5}$$

$$\sum_{k=1}^{K} X_{ijk} \leq 1 \quad , \forall_{i \in I} \ \forall_{j \in J} \tag{6}$$

$$\sum_{j=1}^{J} H_{ijk} \leq C_K \quad , \forall_{i \in I} \ \forall_{K \in K^i} \tag{7}$$

$$T^1{}_{ij} = \frac{Y_{ij} . B_{ij} . A_j}{V_j} \quad , \forall_{i \in I} \ \forall_{j \in J} \tag{8}$$

$$T^2{}_{ij} \geq T^1{}_{ij} \quad , \forall_{i \in I} \ \forall_{j \in J} \tag{9}$$

$$Y_{ij} . M \geq \sum_{K \in K^i}^{K} X_{ijk} \quad , \forall_{i \in I} \ \forall_{j \in J} \tag{10}$$

$$Y_{ij}(bin) \quad , \forall_{i \in I} \ \forall_{j \in J} \tag{11}$$

$$X_{ijk}(bin) \quad , \forall_{i \in I} \ \forall_{j \in J} \ \forall_{k \in K} \tag{12}$$

$$H_{ijk}(gin) \quad , \forall_{i \in I} \ \forall_{j \in J} \ \forall_{k \in K} \tag{13}$$

$$T^2_{ij}(gin) \quad , \forall_{i \in I} \ \forall_{j \in J} \tag{14}$$

The objective function focused on economics for the highest profit of farmers. Objective function (1) consisted of 3 main sequences as following: 1) Function of raw material cost which depended on the purchase price of each crop, cost of each crop cultivation, size of planting area and yield rate, 2) Function of transportation cost which depended on the amount of raw materials, transportation distance to plant, cost of each crop transportation and amount of each crop transportation round, 3) Function of cost of cultivation which depended on budget spent on each crop.

The constraint (2): consisted of Function of limitation that each farmer could only plant one crop. (3): is a Function of limitation that each crop required at least one farmer. (4): is Function of limitation that the amount of crop yield was delivered to a plant must be equal to the amount of crop planted by each farmer. (5): Function of limitation that the amount of crop yield was delivered to a plant must not exceed the amount of crop planted by each farmer. (6): Function of limitation that a farmer could transport the crop by only one route to a plant. (7): Function of limitation that the amount of crop must not exceed the purchase capacity of a plant. (8): Function of limitation that the amount of transportation round must come from yield rate multiplied by the planting area and divided by the capacity of the transport vehicle. (9): Function of limitation that the amount of transportation round must be integer (round). (10): Function of limitation that the maximum yield rate delivered must not be less than the amount of yield rate transport from the farmer to the plant. (11): Function of limitation that which farmer planted each crop was determined by 0 or 1 only, 1 for plant and 0 for others. (12) Decision variables when a farmer transporting each crop to a plant k. (13): Function of limitation that there is an amount of crop i from a farmer j to a plant k. The value is an integer. (14): Function of limitation that the amount of transportation round is an integer.

4. Methodology

4.1 Differential Evolution Algorithm

The researchers used the Differential Evolution algorithm to solve cultivate economic crop planning problems. There were 4 stages as follows:

4.1.1 Generate initial solution

An initial answer to use the initial population to create answers was created. NP is the number of population created to find the answer, in which 1 NP or 1 is equal to one answer for each answer, and the NP created to solve this problem will be in the form of a vector metric that has a vector size equal to the number of farmers and the number of plants to buy all 3 types of crops. The NP is equal to the number of farmers or sub-districts, which is equal to 5 cases in the range [0, 1], which is encrypted with a random number.

An initial answer starting from determining the probability range of crop selection was created by specifying the probability range for 3 periods, which can be changed as follows:

1st period, if the random number is between 0.40 - 0, rice will be planted.

2nd period, if the random number is between 0.70 - 0.41, cassava will be planted.

3rd period, if the random number is between 1.0 - 0.71, sugarcane will be planted as shown in Table 1 and Table 2.

Table 1 Probability of vector random numbers for farmers or sub-districts.

Range of random number*	0 - 0.40	0.41 – 0.70	0.71 – 1.0
Type of crops	rice	cassava	sugarcane

*The total random number is equal to .1

Table 2 Example of crop selection using vector probability range for farmers or sub-districts.

Sequence	Farmers or sub-districts				
	1	2	3	4	n
Random number	0.5	0.1	0.4	0.8	…
Range of period	2	1	2	3	…
Crop	cassava	rice	cassava	sugarcane	…

For population determination, if the quantity of crop is full at the capacity of all plants will change to the crop that has the similar random number.

Once the farmers are decided to grow crops and delivered the products to nearby plant, if the capacity of that plant is full it will deliver to the nearest plant.

4.1.2 Mutation process

Values in target vectors were adjusted by the way that each value of target vector from Table 2 was adjusted by Equation 15 by randomly selecting value at each coordinate of r_1, r_2 and r_3. (15) was the equation used in mutation process of the target vector. When the target vector had been running through the mutation process, new value of each position in coordinate of target vector occurred which was called mutant vector. The mutant vector came from randomly taking of vectors X_{r1}, X_{r2}, X_{r3} which were in the coordinate of vector of each same horizontal row, then the value in (15) was replaced for F value which was the factor level that controlled the different level between the vectors X_{r2}, $X_{r3,}$ before adding to the basic vector X_{r1} which F=2 that was assigned to be the parameters from the study by Qin et al. [11].

$$V_{i,j,G} = X_{r1,j,G} + F(X_{r2,j,G} - X_{r3,j,G}) \quad (15)$$

as $V_{i,j,G}$ mutant vector

X_{r1}, X_{r2} and X_{r3} random vectors

F scaling factor which is set to be 2 in the proposed heuristics

i vector number; i = 1, 2, …., NP

j position within vector; j =0, 2, …., D

4.1.3 Recombination process

When every value of target vector had been modified, next step was found trial vector from the value exchanging process which was at variety recombination stage that could produce both better and worse diversified varieties of answers. The trial vector value ($U_{i,j,G+1}$) was obtained from (16) by random taking of real number, $rand_{i,j}$ from 0 to 1, then the comparison was done by comparing the value of trial vector with the value of CR, CR=0.8 was assigned, which was the parameter from the study of Qin et al. [11] and comparing every position in coordinate of target vector of each vector i. If the comparison result showed that random number was less or equal to the value of CR, the position in that coordinate would be selected as mutant vector value. If the random number was greater than value of CR, the position in that coordinate would be selected as the target vector value.

$$U_{i,j,G} = \begin{cases} V_{i,j,G} \text{ if } rand_{ij} \leq CR \text{ or } j = Irand \\ X_{i,j,G} \text{ if } rand_{ij} > CR \text{ or } j \neq Irand \end{cases} \quad (16)$$

4.1.4 Selection process

Selection process was comparing the result from decoding of trial vector with the one that obtained from target vector. In this study there was an objective equation to find maximum profit in crop planning, searching for locating point of plant. Hence, the selection process would select the answer that gave maximum profit between trial vector and target vector and this new vector would be assigned to be the next generation of target vector (G+1) as (17).

$$X_{i,j,G+1} = \begin{cases} U_{i,j,G} \text{ if } f(U_{i,j,G}) \leq f(X_{i,j,G}) \\ X_{i,j,G} \quad \text{otherwise} \end{cases} \quad (17)$$

4.2 Modified Differential Evolution Algorithm

Modified Difference Evolution algorithm using the Random best algorithm method (MDE-R) is the improvement of DE method at the stage of mutation by collecting random number from the coordinate of best target vector after selection process for using in random taking of values X_{r1}, X_{r2} and X_{r3} in modifying value in each coordinate of target vector of the next round in order to improve answer for better efficiency. Considering DE method, it was found that behavior of answer finding was of diversification type. The values of X_{r1}, X_{r2} and X_{r3} were random numbers of the numbers that taken from position in coordinate of target vector. Hence, the researchers improved area of finding answer by getting random numbers from random numbers of best target vector already collected to get amount of m vectors after selecting of new vector in each round as shown as the following steps:

step 1 Creating initial answer,

step 2 Evaluating the value of fitness function or target equation of target vector,

step 3 Producing new generation of population by the method as step 3.1-3.4 and repeating the steps until terminating condition has been met,

step 3.1 creating mutant vector by modifying values in coordinate of vector by (15) in round 1st by (18) in the next round,

$$V_{i,j,G+1} = X_{r1best,j,G} + F(X_{r2best,j,G} - X_{r3best,j,G}) \quad (18)$$

where X_{r1best}, X_{r2best} and X_{r2best} are random numbers obtained from random numbers of best target vector collected

step 3.2 creating trial vector by exchanging value in coordinate of vector,

step 3.3 selecting target vector in the next round,

step 3.4 collecting random number of best target vector for m vectors.

An experiment was carried on collecting random number of target vector that gave the best answer to be used in random processing of the values X_{r1}, X_{r2} and X_{r3}. This was designed to have the number of random numbers collection of target vector that gave the best answer for m vectors to be 10 sizes of 10 vectors. Finding the answer was done by assigning NP = 50, G = 10,000, F = 2 and CR = 0.8.

5 .Computational experiment and results

The research was done by introducing of DE and MDE-R by using Visual Studio 2017 software in designing algorithms and processing of answers to be used in comparing the result of finding answer of the different sizes of case study problems by a computer with CPU of Inter (R) Core (TM) i3-3240 CPU 3.40 GHz, RAM 4 GB. This was tested with small size problem of 5-20 farmers, medium size problem of 30-60 farmers and large size problem of 70-500 farmers and case study problems of 1,293 farmers (planting area). Answer finding was done by assigning NP = 50, G = 10,000, F = 2, CR = 0.8 in order to get maximum profit by using equal duration of 1.30 hour. The results of DE compared with Lingo V.11 software are shown in Table 3. The solution of the test instances of DE compared with MDE-R as shown in Table 4.

Table 3 Results of Calculation of DE compared with Lingo V.11 software.

Group of problems	Number of farmers	Number of plant			Method				%Diff
		rice	cassava	sugarcane	Lingo		DE		
					Profit (Baht)	Time (second)	Profit (Baht)	Time (second)	
Small size	5	3	3	1	192,540	0:00:01	192,540	0:00:01	0
	5	5	5	2	195,447	0:00:03	195,447	0:00:01	0
	10	5	5	5	549,514	0:00:09	549,514	0:00:04	0
	10	7	7	6	562,636	0:00:12	562,636	0:00:05	0
	10	9	10	6	571,941	0:00:24	571,941	0:00:07	0
	20	8	9	5	$1.70112x10^6$	0:00:23	$1.70112x10^6$	0:00:11	0
	20	10	10	6	$1.70245x10^6$	0:00:28	$1.70245x10^6$	0:00:13	0
	20	15	15	7	$1.72964x10^6$	0:00:35	$1.72964x10^6$	0:00:12	0
Medium size	30	10	20	3	$1.71241x10^6$	0:02:10	$1.71241x10^6$	0:00:13	0
	30	12	25	5	$1.72184x10^6$	0:02:37	$1.72184x10^6$	0:00:12	0
	30	14	27	4	$1.72983x10^6$	0:03:15	$1.72983x10^6$	0:00:14	0
	40	16	30	5	$2.26761x10^6$	0:03:39	$2.26761x10^6$	0:00:26	0
	40	20	40	6	$2.28014x10^6$	0:03:50	$2.28014x10^6$	0:00:49	0
	40	25	45	5	$2.45279x10^6$	0:03:38	$2.45279x10^6$	0:04:32	0
	50	25	45	6	$2.88381x10^6$	0:03:56	$2.88381x10^6$	0:03:07	0
	50	30	50	8	$2.89783x10^6$	0:04:03	$2.89783x10^6$	0:02:11	0
	60	30	50	5	$2.91543x10^6$	0:04:50	$2.91543x10^6$	0:01:33	0
	60	35	55	7	$2.94427x10^6$	0:05:49	$2.94427x10^6$	0:01:48	0
Large size	70	35	55	3	$3.95603x10^6$	0:09:45	$3.95603x10^6$	0:03:32	0
	70	40	60	5	$3.97597x10^6$	0:11:48	$3.97597x10^6$	0:03:45	0
	70	45	65	7	$3.97372x10^6$	0:12:16	$3.97372x10^6$	0:03:41	0
	70	50	70	10	$3.98929x10^6$	0:12:34	$3.98929x10^6$	0:03:36	0
	80	45	60	5	$4.59883x10^6$	0:15:36	$4.59883x10^6$	0:03:28	0
	80	50	70	7	$4.59763x10^6$	0:18:49	$4.59763x10^6$	0:03:17	0
	80	55	70	10	$4.59916x10^6$	0:21:22	$4.59916x10^6$	0:03:44	0
	100	50	70	7	$5.31524x10^6$	> 250 Hrs.	$5.31524x10^6$	0:10:19	-
	100	60	80	10	$5.33877x10^6$	> 250 Hrs.	$5.33877x10^6$	0:13:21	-
	100	70	90	15	$5.34643x10^6$	> 250 Hrs.	$5.34643x10^6$	0:16:34	-

Table 4 Profits in solving various size problems with DE and MDE-R using the same time intervals.

Group of problems		Profit (Baht)	
		DE	MDE-R
Small size	5 (3-3-1)	192,540	192,540
	10 (3-3-4)	544,934	545,392
	15 (3-3-4)	571,941	572,528
	20 (7-7-5)	$1.70112x10^6$	$1.70112x10^6$
Medium size	30 (16-30-5)	$2.26761x10^6$	$2.26761x10^6$
	40 (15-15-7)	$2.91543x10^6$	$2.92264x10^6$
	60 (35-55-3)	$3.95603x10^6$	$3.95603x10^6$
Large size	70 (45-60-5)	$4.59883x10^6$	$4.59994x10^6$
	100 (50-50-10)	$5.31524x10^6$	$5.31680x10^6$
	500 (60-70-10)	$9.44262x10^6$	$9.47244x10^6$
Case study	1,293 (70-90-15)	$12.69587x10^6$	$12.76052x10^6$

6. Conclusion

The problem solving of crop planning and locating of processing plants for production of rice, cassava, and sugarcane in Northeastern of Thailand by DE and MDE-R methods to obtained highest profit, tested with groups of problem by small, medium and large size and case study problem. The result found that when the problem size was larger, MDE-R method had better efficiency in finding the answer than DE method in term of maximum value. Therefore, comparing the efficiency in finding answer by DE and MDE-R methods was done, it was probably that adding collecting value of Random best algorithm could help to improve to finding the answer method. The small size problem had a narrow gap in finding answer due to low population, thus searching the best answer was the same as optimal solution but when the problem became larger, the optimal solution method could not search the answer within the limited time, while MDE-R could find the answer better and consumed less time. To increase collecting the random value that gave the best answer in each round by Random Best algorithm would reduce the gap or intensification in finding answer that enable to find the best answer. For this problem, the 175 plants which were classified into 70 plants for rice process, 90 for cassava process and 15 plants for sugarcane process would also be suggested. The maximum profit was 12,760,520 baht per production cycle.

7. References

[1] Agricultural Information, Bangkok: Office of Agricultural Economics, 2018.

[2] Qin, A. K. and Suganthan, P. N. "Self-adaptive differential evolution algorithm for numerical optimization", In Proceedings of the 2005 IEEE Congress on Evolutionary Computation. p. 1785–1791. Edinburgh, Scotland: IEEE Xplore, 2005.

[3] Chakraborty, U. K. and et al. Differential evolution with local neighborhood. New Jersey: IEEE Press, 2006.

[4] Josiah, A. and Fred, O. "Differential evolution algorithm for solving multi-objective crop planning model", Journal of Agricultural Water Management. 97(6): 848-856; June, 2010.

[5] Zou, D. and et al. "An improved differential evolution algorithm for the task assignment problem", Engineering Applications of Artificial Intelligence. 24(4): 616-624; June, 2011.

[6] Pitakaso, R. and Thongdee, T. "Solving a multi-objective, Source & Stage location- allocation Problem using Differential Evolution" In Proceeding of the Asoa Pacific Industrial Engineering & Management Systems Conference 2012: p. 1053-1060. Ubon Ratchathani: Ubon Ratchathani University, 2012.

[7] Thongdee, T. H. and Pitakaso, R. "Solving a multi-objective, source & stage location-allocation problem: a case study of a bagasse and cassava pulp ethanol plant in northeastern Thailand", Asia-Pacific Journal of Science and Technology. 17(1): 71-87; February, 2012.

[8] Su, Z. and et al. "Multiple emergency resource allocation for concurrent incidents in natural disasters", International Journal of Disaster Risk Reduction. 17(1): 199-212; January, 2016.

[9] Sethanan, K. and Pitakaso, R. "Improved differential evolution algorithms for solving generalized assignment problem", Expert Systems with Applications. 45(3): 450-459; March, 2016b.

[10] Dechampai, D. and et al. "A differential evolution algorithm for the capacitated VRP with Flexibility for mixing pickup and delivery services and the maximum duration route in poultry industry", Journal of Intelligent Manufacturing. 28(6): 1357-1376; August, 2017.

[11] Qin, A. K. and et al. "Differential evolution algorithm withstrategy adaptation for global numerical optimization", IEEE Transactions on Evolutionary Computation. 13(2): 398–417; April, 2009.

[12] Ketsripongsa, U. and et al. "An Improved Differential Evolution Algorithm for Crop Planning in the Northeastern Region of Thailand", Journal of Mathematical and Computational Application. 23, 40; doi:10.3390/mca23030040, 2018.

[13] Kaewman, S. and et al. "Differential Evolution Algorithm for Multilevel Assignment Problem: A Case Study in Chicken Transportation", Journal of Mathematical and Computational Application. 23, 55; doi:10.3390/mca23040055, 2018.

[14] Srivarapongse, T. and Pijitbanjong, P. "Solving a Special Case of the Generalized Assignment Problem Using the Modified Differential Evolution Algorithms: A Case Study in Sugarcane Harvesting", Journal of Open Innovation: Journal of Technology, Market, and Complexity. 5, 5; doi:10.3390/joitmc5010005, 2019.

[15] Thongkham, M. and Srivarapongse, T. "Improved Differential Evolution Algorithm to Solve the Advertising Method Selection Problem", Journal of Technology, Market, and Complexity. 5, 61; doi:10.3390/joitmc5030061, 2019.