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Improvement of a Distribution System Using a Heuristic Method: A Case Study

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Abstract

In this paper, we consider a two-echelon distribution system in Thailand. Currently, this system consists of 7 facilities, 77 distribution centers, and 928 retailers. The company would like to redesign the distribution system in order to minimize total travelling distance. The decisions for the company are 1) locating distribution centers, 2) allocating distribution centers to each facility and allocating retailers to each distribution center, and 3) assigning delivery routes for distribution centers. A mathematical formulation of this problem has been constructed. Due to the complexity of this problem, a heuristic method is proposed. The result indicates that the proposed heuristic method reduced the total travelling distance approximately 20.64% from the current plan. In addition, we investigate the effect of number of distribution centers on the travelling distance and compare the results with the solution obtained from the genetic algorithm (GA). The results show that our proposed method provides shorter travelling distance for most cases and has shorter computational time.

Keywords: Two-echelon location-routing problem, heuristic optimization, genetic algorithm.

1. Introduction

Distribution is one of the important activities in the logistic. The role of distribution is to manage the flows of products from suppliers towards end customers. It is commonly known that logistic cost is a large part of the company's costs. This cost can be reduced by a careful design of distribution network. Two important questions arise when designing the distribution network. First where to locate the facilities and which vehicle routes should be used. The problem related to the first question is referred to as the location-allocation problem (LA). When the routing is the only decision, then the problem is referred to as the vehicle routing problem (VRP). These two problems have been considered separately for a long time. When the location planning and the vehicle routing are simultaneously considered the problem becomes the location-routing problem (LRP). Thus, the LRP is a combination of LA and VRP and both problems are NP-hard (Non-deterministic polynomial-time hardness).

The study of LRP is crucially important because making a decision on the locations of facilities and vehicle routes cannot be treated without affecting the other (Baldacci et al., 2011). Nagy and Shalhi (2007) mention that some researchers may not agree to combine LA and VRP since their planning horizon are different. They investigate this issue and find that considering both problems simultaneously provides the lower costs over a long planning horizon. Surveys of LRP are presented in Nagy and Salhi (2007), Prodon and Prins (2014), Cuda et al. (2015) and recently Schneider and Drexl (2017). Most studies consider various methods and various versions of LRP to determine the number and the location of facilities, routing and the allocation of customers to the facilities. Due to the complexity of the LRP, exact solutions can only be obtained for small instances (Hassanzadeh et al. 2009). Heuristics are required to obtain appropriate solutions in acceptable running times on the large instances. For example, Tuzun and Burke (1999) propose an algorithm based on Tabu search to solve LRP with uncapacitated depots by using two-phase approach. Wu et al. (2002) develop a heuristic method to multi-depot LRP with different vehicle types. The heuristic method proposed by Lam and Mittenthal (2013) consider a three-phase heuristic containing a clustering phase to assign customers to suitable facilities. Karaoglan et al. (2012) use a heuristic method to consider LRP with simultaneous pickup and delivery. They applied simulated annealing (SA) as a local search algorithm to improve the routing. These works consider single echelon which is defined as standard location-routing problem or classical location-routing problem.

To the best of our knowledge, there are limited works found in literature on two-echelon network of LRP (2E-LRP). This network may be composed of facilities, distribution centers (DC) and end customers. In such a problem, locations of facilities and DCs and travelling routes are needed to distribute products in supply chain. Although 2E-LRP is first introduced by Jacobsen and Madsen (1980) and Madsen (1983), no other work has studied 2E-LRP until Lin and Lei (2009). The 2E-LRP and its variants are very hard optimization problems which are seldom investigated (Prodhon and Prins, 2014). Recently, many researchers pay more attention to two-echelon location routing problems (2E-LRP). Govindan et al. (2014) consider a 2E-LRP with time windows to a supply chain of perishable food. They apply a hybrid multi-objective algorithm to the problem. Rath and Gutjahr (2014) consider an application of the 2E-LRP. The objective is to select intermediate locations for distributing relief goods when disaster occurs. They formulate their problem as the multi-objective optimization problem by minimizing total travelling distance from facility to DCs and maximizing the coverage demand. They combine a variable neighborhood search (VNS) and exact method. The closet work to ours is the work by Vidović et al. (2016). They study a 2E-LPR for recycling logistics networks. The first level considers sending recyclable disposal from collection points to transfer stations. The second level deals with collecting recyclable disposal from end users to collection points. They determine suitable locations of both collection points and transfer stations to maximize profit. Unlike our network, their network is short and simple. They assume that end users are located in city blocks and the vehicles are not allowed to serve more than four blocks in each route. The routing in the second level is a direct route and a simple ARC routing algorithm is used to find the optimal route.

In our work, we consider a distribution system in Thailand which consists of facilities, DCs, and retailers. Both routing design and DC location must be determined simultaneously. To be more specific, the location of the DCs, the allocation of service coverage of DCs and facilities, and the construction of the delivery routes are the company’s decisions. The objective is to propose a heuristic method to improve the travelling distance of the distribution system in Thailand. The advantages of the proposed method are its simplicity and applicability. Moreover, the coordination between location and route improvement can provide better solutions.

The remainder of this paper is organized as follows. Section 2 presents mathematical formulation for solving the problem. Then the proposed heuristic method for finding good feasible solutions of this problem is given in Section 3. Results and conclusions are shown in Sections 4 and 5, respectively.

2. Mathematical Formulation

The problem considered in this paper is defined as follows. Facilities store goods and send products through distribution centers (DCs). Different types of vehicles perform tours to supply DCs. Each retailer travels directly to one of DCs or to the facility to pick up the product. Potential locations of distribution centers are known. However, a number of opened DCs is limited due to many constraints. The supplier needs to make decisions on the locations of DCs, allocation of DCs to each facility, and the delivery routes. In addition, the supplier must determine what the service coverage is for each DC. Our goal is to minimize the total travelling distance which includes both tour distance from facilities to DCs and roundtrip distance between retailers' locations and the DCs. In this section, we first formulate a mathematical model as a mathematical programming. Assumptions of this problem are as follows. Each retailer must be served by a facility or a DC located within the maximum distance (due to the regulation).

Notations used in the model are defined as follows. Indices i and j represent node i and node j, respectively. In our model, nodes include facilities, potential DCs and retailers. An index m refers to facility m. An index k represents vehicle k.

Sets

C set of retailers

M set of facilities

W set of potential distribution centers

V_m set of number of vehicles at facility m

Parameters

N number of potential locations

P number of opened distribution centers

D_{ij} distance from node i to node j (asymmetric)

L the maximum allowable round-trip distance between each retailer and a distribution center

Decision variables

$$y_i = \begin{cases} 1, & \text{if main facility or potential distribution centers } i \text{ is selected to open} \\ 0, & \text{otherwise} \end{cases}$$

$$z_{ij} = \begin{cases} 1, & \text{if main facility or distribution center } i \text{ serves customer } j \\ 0, & \text{otherwise} \end{cases}$$

$$a_{mi} = \begin{cases} 1, & \text{if distribution center } i \text{ is allocated to main facility } m \\ 0, & \text{otherwise} \end{cases}$$

$$x_{ijk} = \begin{cases} 1, & \text{if } i \text{ immediately precedes } j \text{ on vehicle } k \\ 0, & \text{otherwise} \end{cases}$$

u_{ik} non-negative variable to prevent sub-tour for vehicle k.

The problem formulation is as follows:

Minimize $\sum_{i\in M\cup W}\sum_{j\in C}\left(D_{ij}+D_{ji}\right)z_{ij}+\sum_{m\in M}\sum_{i\in\{m\}\cup W}\sum_{\substack{j\in\{m\}\cup W\\ j\neq i}}\sum_{k\in V_m}D_{ij}x_{ijk}$

s.t. $\sum_{i\in W}y_i=P$ (1)

$y_i=1 \qquad \forall i\in M$ (2)

$z_{ii}=y_i \qquad \forall i\in M\cup W$ (3)

$\left(D_{ij}+D_{ji}\right)z_{ij}\le Ly_i \qquad \forall i\in M\cup W,\forall j\in C,i\neq j$ (4)

$\sum_{i\in M\cup W}z_{ij}=1 \qquad \forall j\in C$ (5)

$\sum_{i\in M}a_{mi}=y_i \qquad \forall i\in W$ (6)

$\sum_{i\in W}\sum_{k\in V_m}x_{ijk}=a_{mi} \qquad \forall m\in M,\forall j\in W,j\neq i$ (7)

$\sum_{\substack{j\in\{m\}\cup W\\ j\neq i}}x_{jik}=\sum_{\substack{j\in\{m\}\cup W\\ j\neq i}}x_{ijk} \qquad \forall m\in M,\forall i\in\{m\}\cup W,\forall k\in V_m$ (8)

$u_{ik}-u_{jk}+\left(N+1\right)x_{ijk}\le N \qquad \forall m\in M,\forall i,j\in W,i\neq j,\forall k\in V_m$ (9)

$y_i\in\{0,1\} \qquad \forall i\in M\cup W$ (10)

$z_{ij}\in\{0,1\} \qquad \forall i\in M\cup W,\forall j\in C$ (11)

$a_{mi}\in\{0,1\} \qquad \forall m\in M,\forall i\in W$ (12)

$x_{ijk}\in\{0,1\} \qquad \forall m\in M,\forall i,j\in\{m\}\cup W,i\neq j,\forall k\in V_m$ (13)

$u_{ik}\ge 0 \qquad \forall m\in M,\forall i\in W,\forall k\in V_m$ (14)

The objective function is to minimize the total distance which includes both supplier and retailer travelling distance. First term is the total round-trip distance between each retailer and a DC located in its coverage area. Second term represents supplier travelling distance which is the total length of all closed-loop tours among each facility and DCs in the coverage area. Constraint (1) specifies the total number of DCs to be opened. Constraint (2) indicates that a facility can act as a DC; that is, it can serve retailers located nearby. Constraint (3) specifies that each facility or DC must serve retailers who are assigned to its coverage area. According to Constraint (4), each retailer cannot travel further than the maximum distance allowed. In addition, each retailer is served by only one facility or a DC as shown in Constraint (5). From Constraint (6), each facility must serve all DCs located in its coverage area. Restrictions of deliveries from facilities to DCs are mentioned in Constraints (7)-(9). Constraint (7) guarantees that each DC is visited once. On the other hand, there is no route visiting each potential DC if it is not opened. Constraint (8) ensures that when a vehicle enters any DCs, it has to leave that facility. The sub-tour elimination constraint for each route is given by Constraint (9). Constraints (10)-(14) are decision variables constraints.

3. Proposed Heuristic Method

As shown in previous section, the problem is dealing with the combination of complex constraints. This problem is non-trivial and it is an NP-hard problem. The large-sized location-routing problem can hardly be solved by exact methods. As a result, a heuristic approach is developed to obtain the solution. This proposed method is easy to implement and provides the reasonable solutions within reasonable time. Figure 1 shows the pseudocode for the proposed algorithm which consists of two phases: Initialization and Improvement phases. In the initialization phase, an initial solution is obtained. This solution is feasible to the problem. These feasible locations are determined by using the algorithm proposed by Dantrakul and Likasiri (2012). It provides the minimum number of opened DCs needed by gradually selecting a potential DC to open until it covers all retailers and satisfies all constraints. Then all delivery routes from facilities to all chosen locations are constructed using the Nearest Neighbor Algorithm (NNA) (Rosenkrantz et al. 1977) which is based on greedy algorithm. It starts with the facility and then chooses the closest DC to be the next visit in the delivery route. This selection is repeated until all DCs are visited.

In the improvement phase, the new solution is developed by randomly select from one of two approaches, named switch locations or remove-add location. The switch location approach is a procedure to find the shorter route by changing the order of DCs in the route. Thus, the set of DCs is not changed. Two DCs on the same route are selected randomly then one of the following strategies is performed.

- swapping the orders of these DCs
- rerouting the orders between these DCs
- moving one of these DCs to the last DC visited in the route.

The remove-add location approach is a procedure that deletes one DC from the route and replaces the potential DC into the route. If the new route improves the solution, then continue to the next iteration. Otherwise, NNA is applied to this new set of DCs. If the new route improves the solution, then continue to the next iteration. Otherwise, switch locations approach is considered. The improvement phase is repeated until one of the stopping criteria is met. The algorithm terminates when the maximum iterations, $MaxI$, is reached or the improvement of distance between iterations is less than the specified small value ε for T iterations. Pseudocode of the algorithm is shown in Figure 1.

4. Results and Discussion

This section is divided into two subsections. In Subsection 4.1, the performance of the proposed heuristic method is investigated. To be more specific, the solutions of the exact method and the proposed method are compared as well as their computational times. In Subsection 4.2, the heuristic method is implemented to the distribution system in Thailand.

4.1. Small LRP problem

The optimal solution can be obtained for small substance. Thus, in this section, we compare our heuristic result with the exact solution for the small problems in order to investigate the performance of the heuristic method in 2E-LRP. We consider two examples: S1 and S2. S1 consists of one facility, 40 potential locations of DCs and 40 retailers. There are two facilities, 30 potential locations of DCs and 30 retailers in S2. The objectives are to find location of DCs and to allocate service coverage of DCs and facilities while minimizing the travelling distance. The exact solution is obtained by using LINGO 13.0 which applies the branch-and-bound method to the mathematical model formulated in Section 2. The proposed method is run for 500 replications for each case. The stopping criteria are the maximum iteration is 50,000 iterations and the minimum gap is 0.01%. The proposed method is terminated when it reaches the maximum iteration or the total distance of the solution reduced less than 0.01% in 10,000 iterations. Both LINGO 13.0 and our method are run on a 2.20 GHz Intel® Core™2 Duo Processor T6600 CPU, 2 GB RAM and Windows 7 Home Premium.

```
BEGIN
INPUT   P (the number of intermediate facilities)
SET     MaxI (the maximum iteration)
        ε (the minimum gap)
// Construct the initial solution s
 s ← Initial Solution (P)
iteration = 1
REPEAT
    // Generate a trial solution s′
    Choose a strategy k randomly; k = 1 or 2
    CASE k = 1:  s′ ← Route Improvement (s)
                 IF f (s′) < f (s) THEN s ← s′ END IF
    END CASE k = 1
    CASE k = 2:  s′ ← Remove-Add Location (s)
                 IF f (s′) < f (s) THEN s ← s′ END IF
                 ELSE
                     s″ ← NNA (s′)
                     IF f (s″) < f (s) THEN s ← s″ END IF
                     ELSE
                         s″ ← Route Improvement (s′)
                         IF f (s″) < f (s) THEN s ← s″ END IF
                     END ELSE
                 END ELSE
    END CASE k = 2
INCREMENT iteration
UNTIL iteration > MaxI or Δf(s) < ε
```

Figure 1 Algorithm of the proposed method

Table 1 Number of nodes in small-sized examples

Example	Part of region	No. of facilities	No. of potential DCs	No. of retailers
S1	Northern	1	40	40
S2	Southern	2	30	30

Table 2 presents twelve cases with the various numbers of DCs of Example S1. The solutions obtained from the proposed method are the same as the optimal solutions in all cases. The average running time of the proposed method for each case is less than a second. However, in some cases, LINGO 13.0 takes almost 9 hours to find the optimal solution.

Next, example S2 is investigated. In this case, there are two facilities in the region. The solutions obtained from the proposed method and the optimal solutions are the same when the number of opened DCs is small as shown in Table 3. In addition, the computational time of the exact method solved by LINGO 13.0 increases exponentially. It takes almost 13 days to obtain the optimal solution when nine DCS are allowed to be opened. When the number of opened DCS is 10 or larger, LINGO 13.0 does not provide the optimal solution within 14 days. However, the running time for the proposed method is within few seconds.

It can be seen in Table 3 that when the problem is large, the exact solution cannot be obtained within reasonable time in practice.

Table 2 Comparison of results from the exact and proposed methods for S1

No. of opened DCs	LINGO 13.0		Proposed method	
	Optimal solution (km.)	Running time (sec.)	Best found solution (km.)	Average running time (sec.)
4	3,884.31	2	3,884.31	0.124
7	3,149.59	48	3,149.59	0.244
10	2,704.97	121	2,704.97	0.352
13	2,455.94	2,810	2,455.94	0.441
16	2,268.87	16,142	2,268.87	0.569
19	2,105.72	25,919	2,105.72	0.625
22	1,969.71	20,729	1,969.71	0.656
25	1,869.82	12,684	1,869.82	0.668
28	1,798.72	32,171	1,798.72	0.730
31	1,755.50	2,207	1,755.50	0.809
34	1,723.07	5,077	1,723.07	0.836
37	1,714.34	13,681	1,714.34	0.847

Table 3 Comparison of the exact method and proposed method for Example S2

No. of DCs	LINGO 13.0		Proposed method	
	Optimal solution (km.)	Running time (sec.)	Best found solution (km.)	Average running time (sec.)
6	4,824.09	19	4,824.09	0.90
7	4,568.26	4,202	4,568.26	1.05
8	4,376.04	102,603	4,376.04	1.38
9	4,212.47	744,582	4,212.47	1.68
10	-	-	4,060.94	1.69
11	-	-	3,918.69	1.96
12	-	-	3,782.18	2.13
13	-	-	3,653.36	2.35
14	-	-	3,535.25	2.22

"-" means cannot obtain the optimal solution within 14 days.

4.2. A case study

In this subsection, the proposed algorithm is implemented to a real-world problem. We consider a distribution system in Thailand. There are 7 facilities located throughout the country. One of them is located in the Northern region, two are in the Northeastern region, two are in the Southern region, and others are in the Central region. Note that there is no facility located in the Eastern region. However, one facility located in Central produces this product for the Eastern region. Each facility is also acted as a DC; that is, it can serve retailers located nearby. Currently, there are 77 DCs (including 7 facilities), one in each province, and 928 retailers. Figure 2 shows the locations of facilities and retailers of the distribution system.

Each DC has its own vehicles. Thus, they pick up the product from the assigned facility every month. Similarly, each retailer travels to the distribution center directly. Details of the travelling distances for each region are shown in Table 4.

Table 4 Travelling distances in current setting (in km.)

Region	No. of facilities |M|	No. of retailers |C|	Retailers' distance	DCs' distance	Total distance
Eastern	1*	63	4,152.46	2,517.58	6,670.04
Northern	1	103	11,132.60	2,400.28	13,532.88
Southern	2	151	12,054.21	3,797.33	15,851.54
Central	2	289	19,127.32	5,827.09	24,954.41
Northeastern	2	322	30,739.23	5,568.78	36,308.01

* The facility is located in the Central region.

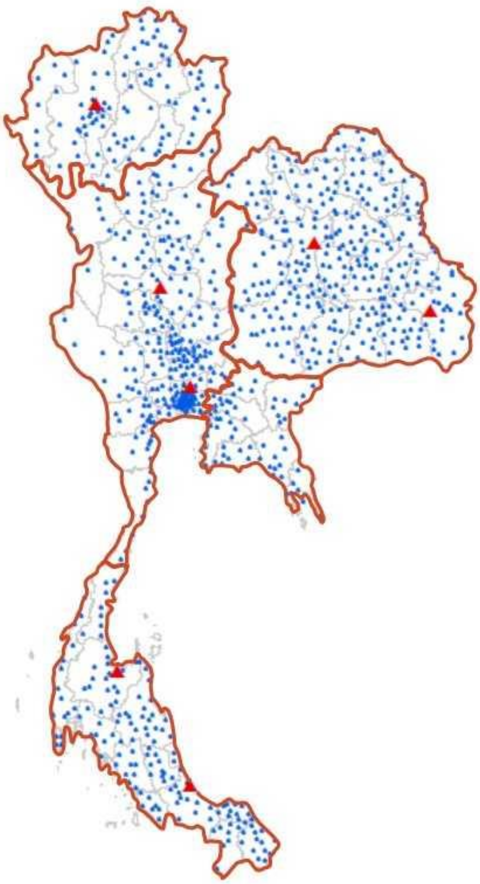

Figure 2 Locations of the facilities and retailers of the studied distribution system

Recall that our objective is to improve the total travelling distance of the current distribution system. We first try to improve the travelling distance from facility to all distribution centers by performing a tour using NNA method. This problem becomes the 2E-VRP. The locations of DCs are fixed as in the current system. The results of each region are shown in Table 5.

Table 5 Travelling distance using NNA with current distribution centers

Region	No. of facilities	No. of DCs	Farthest distance (km.)	No. of retailers exceed L	Travelling distance (km.)				
					Total distance	Retailers' distance	DCs' distance	Route 1	Route 2
Eastern	1*	7	178.38	0	4,966.18	4,152.46	813.72	813.72	-
Northern	1	8	372.68	8	12,334.69	11,132.60	1,202.09	1,202.09	-
Southern	2	14	267.67	1	13,872.50	12,054.21	1,818.29	413.03	1,405.26
Central	2	28	490.15	8	21,195.07	19,127.32	2,067.75	1,120.50	947.25
Northeastern	2	20	218.24	0	32,630.44	30,739.23	1,891.21	240.22	1,650.99
Total	7	77		17	84,998.88	77,205.82	7,793.06		

It can be seen that using NNA method to create the tour from facility to all distribution centers and comes back to the facility can reduce the travelling distance. Since the locations of distribution centers are same as in the current system, then the retailers' distance which is the total distance between each retailer and distribution centers remains the same. NNA method can reduce the DCs' distance 1,703.86 km. in the Eastern region, 1,198.19 km. in the Northern region, 1,979.04 km. in the Southern region, 3,759.34 km. in the Central region, and 3,677.57 km. in the Northeastern region. The reduction percentages are 67.68%, 49.92%, 52.12%, 64.51%, and 66.04%, respectively. Improving the tour route of distribution centers and fixing the location of the distribution centers reduces only the DCs' distance but does not reduce the retailers' distance. In the next section, changing the locations of distribution centers is allowed.

4.2.1 Heuristic implementation

In this section, the locations of DCs are allowed to change. This problem becomes the 2E-LRP. Heuristic method proposed in Section 3 is implemented.

Table 6 Travelling distance of the current system and the proposed heuristic method (in km.)

Region	Current			Proposed method			Saving		
	Retailer	Distribution center	Total	Retailer	Distribution center	Total	Retailer	Distribution center	Total
Eastern	4,152.46	2,517.58	6,670.04	3,740.89	803.92	4,544.81	411.57 (9.91%)	1,713.66 (68.07%)	2,125.23 (31.86%)
Northern	11,132.60	2,400.28	13,532.88	10,849.14	1,347.77	12,196.91	283.45 (2.55%)	1,052.51 (43.85%)	1,335.97 (9.87%)
Southern	12,054.21	3,797.33	15,851.54	11340.32	1608.58	12,948.90	713.89 (5.92%)	2,188.75 (57.64%)	2,902.64 (18.31%)
Central	19,127.32	5,827.09	24,954.41	15,915.58	3,144.13	19,059.71	3,211.74 (16.79%)	2,682.96 (46.04%)	5,894.70 (23.62%)
Northeastern	30,739.23	5,568.78	36,308.01	26,540.57	1,935.33	28,475.90	4,198.66 (13.66%)	3,633.45 (65.25%)	7,832.11 (21.57%)

The total distance of each region reduces. The reduction for the retailers' distance ranges between 283.45 km. and 4,198.66 km. The reductions for the DCs' distance are between 1,052.51 km. and 3,633.45 km. The largest reductions for both retailers' distance and DCs' distance are in the Northeastern region. The savings of the total distance are 2,125.23 km. or about 31.86% in the Southern region, 1,335.97 km. or 9.87% in the Northern region, 2,902.64 km. or 18.31% in the Southern region, 5894.7 km. or 23.62% in the Central region, and 7,832.11 km. or 21.57% in the

Northeastern region. Implementing the heuristic method can save 20,090.65 km. or 20.64% of the current system in total.

4.2.2 Effect of number of DCs on the total distance

In this section, the effect of number of opened DCs on the DCs' distance, the retailers' distance, and the total distance for each region is investigated. In addition, the performance of the proposed method is compared with the genetic algorithm (GA), a population-based metaheuristic method developed by Halland (1992). The processes of GA contain selection, crossover and mutation, which are inspired from natural selection, a mechanism of evolution. GA is a commonly-used method because it provides good enough solutions in a short time and can be implemented to various problems, including VRP and LRP (Boussaïd et al. (2013), Yildiz et. al. (2013), and Karakatič and Podgorelec (2015)). Lopes et al. (2016) perform comparative study of GA and other heuristic approaches on three sets of standard benchmark sets for the standard LRP. According to Lopes et al. (2016), GA is a competitive method for solving benchmark instances of standard LRP.

For each region, the proposed method and GA are implemented and run for 30 replications. For each replication, the stopping criterion for the both methods either the maximum number of iterations is 50,000 or the improved distance ε is less than 0.01% for 10,000 iterations. For the GA, the total distance of solution is used to evaluate fitness. The population size is 30. We apply tournament selection for choosing each parent and use UX crossover with crossover probability 0.5.

The total distance and average running time for each region are shown in Table 7. The smallest number of DCs in the Eastern region needed to satisfy all constraints is 3. In this case, the total distances are the same for both GA and proposed method. Similar results are obtained when the numbers of DCs are 4 and 5. However, when the number of DCs is larger, the proposed method provides the better total distance. In addition, the proposed method provides better solutions in the Northern, Southern, Central, and Northeastern regions. It is not surprising that when the number of DCs increases, total distances for both GA and proposed method decrease. However, the proposed method provides the lower total distance than GA in the range of 0.19% to 6.05%.

The running time of the proposed method is better than that of GA for most cases as shown in Table 7. Since the GA acquires initial solutions by random, it takes longer time to find feasible solutions. For example, when there are 12 opened DCs in the Central region, it takes more than 30 minutes for GA to find feasible initial solutions. On the other hand, the proposed method can find the initial solution which is also feasible within one minute.

The retailers' distance and the DCs' distance for each region are investigated separately in Table 8. Recall that the retailers' distance is a round-trip while the delivery route of the supplier is a tour. When increasing number of opened DCs, it would reduce the retailers' distance but the supplier must travel longer as shown in Table 8. Since the number of retailers is much larger than the number of DCs, then the retailers' distance is much larger than the DCs' distance. This results in the reduction of total distance when the number of DCs increases. Table 8 shows that the proposed method provides better solutions for both retailers' distance and DCs' distance in most cases.

Table 7 Comparison of the proposed method and the genetic algorithm

Region	No. of potential DCs	No. of ended DCs	Genetic algorithm		Proposed method		
			Total distance of best found solution (km.)	Average running time (sec.)	Total distance of best found solution (km.)	Average running time (sec.)	Saving distance from GA (%)
Eastern	63	3	7,271.78	0.69	7,271.78	0.19	0.00
		4	6,012.74	1.09	6,012.74	0.23	0.00
		5	5,412.74	1.30	5,412.74	0.30	0.00
		6	4,866.03	1.91	4,860.42	0.35	0.12
		7	4,550.22	2.27	4,544.81	0.41	0.12
Northern	102	8	11,558.42	55.36	11,296.45	0.49	2.27
		9	10,725.85	8.45	10,318.14	0.51	3.80
		10	10,176.79	3.16	9,607.69	0.61	5.59
		11	9,770.39	2.23	9,181.52	0.69	6.03
		12	9,382.28	1.95	8,814.49	0.90	6.05
Southern	149	7	16,827.71	19.30	16,786.19	1.72	0.25
		8	15,893.76	11.24	15,741.89	0.70	0.96
		9	15,038.62	11.00	14,796.17	0.85	1.61
		10	14,376.41	9.11	14,100.88	1.00	1.92
		11	13,572.84	14.71	13,411.27	1.08	1.19
		12	13,192.95	16.35	12,948.90	1.04	1.85
		13	12,967.77	15.35	12,506.19	1.03	3.56
		14	12,535.00	3.01	12,075.48	1.31	3.67
Central	287	12	29,348.09	2,503.81	29,258.21	1.25	0.31
		13	27,935.20	436.83	27,188.59	1.52	2.67
		14	26,539.63	122.59	25,913.71	1.75	2.36
		15	25,795.29	40.87	25,091.44	1.81	2.73
		16	24,982.78	22.73	24,073.95	2.13	3.64
		17	24,323.55	443.19	23,220.82	2.48	4.53
		18	23,658.86	131.64	22,566.21	2.65	4.62
		19	22,982.34	141.70	21,901.97	3.35	4.70
		20	22,539.62	88.76	21,307.14	3.07	5.47
Northeastern	320	9	39,074.31	2,624.73	37,790.90	1.50	3.28
		10	36,859.55	458.73	36,166.17	1.76	1.88
		11	35,503.70	78.89	34,577.70	2.15	2.61
		12	34,190.30	25.81	33,481.50	1.98	2.07
		13	33,344.86	15.68	32,516.00	2.76	2.49
		14	32,502.67	11.60	31,480.00	2.71	3.15
		15	31,782.41	11.71	30,477.44	2.57	4.11
		16	31,120.67	10.00	29,780.83	3.30	4.31
		17	30,036.18	11.56	29,145.05	3.37	2.97
		18	29,704.19	10.75	28,475.90	3.32	4.14
		19	29,112.12	12.89	27,906.53	3.97	4.14
		20	28,358.64	13.68	27,300.32	3.93	3.73
		Average		189.66		1.71	2.79

5. Conclusions

In this paper, we improve the distribution system which consists of 7 facilities, 77 DCs, and 928 retailers located around Thailand. The problem is a two-echelon supply chain. The company divides the delivery area into five regions. In each region, products are delivered from facilities to DCs and then the retailers pick up the product at the closet DC. Our objective is to reduce the total travelling distance of this system. If the current locations of the DCs is fixed and the tour delivery routes from facilities to current DCs are determined, the problem becomes 2E-VRP. The results show that applying NNA method to the distribution system can reduce 1,703.86 km. in the Eastern region, 1,198.19 km.

in the Northern region, 1,979.04 km. in the Southern region, and 3,759 km. in the Central region. The total DCs’ distance reduces from 20,111.06 km. to 7,793.06 km. The reduction is about 61.25%. This results in the reduction of the total distance 12.65%.

Table 8 Travelling distance of the solutions (in km.)

Region	No. of opened DCs	Genetic algorithm				Proposed method			
		Total retailers’ distance	DCs’ distance			Total retailers’ distance	DCs’ distance		
			Total	Route 1	Route 2		Total	Route 1	Route 2
Eastern	3	6,604.80	666.98	666.98	-	6,604.80	666.98	666.98	-
	4	5,319.25	693.49	693.49	-	5,319.25	693.49	693.49	-
	5	4,632.96	779.78	779.78	-	4,632.96	779.78	779.78	-
	6	4,058.83	807.20	807.20	-	4,058.83	801.59	801.59	-
	7	3,740.89	809.33	809.33	-	3,740.89	803.92	803.92	-
Northern	8	9,967.67	1,590.75	1,590.75	-	9,968.31	1,328.14	1,328.14	-
	9	8,917.29	1,808.56	1,808.56	-	8,898.86	1,419.28	1,419.28	-
	10	8,204.72	1,972.07	1,972.07	-	8,171.90	1,435.79	1,435.79	-
	11	7,729.54	2,040.85	2,040.85	-	7,728.18	1,453.34	1,453.34	-
	12	7,537.56	1,844.72	1,844.72	-	7,335.98	1,478.51	1,478.51	-
Southern	7	15,449.49	1,378.22	852.12	526.10	15,406.92	1,379.27	860.31	518.96
	8	14,357.63	1,536.13	770.63	765.50	14,335.76	1,406.13	887.17	518.96
	9	13,398.00	1,640.62	519.87	1,120.75	13,398.00	1,398.17	879.21	518.96
	10	12,576.01	1,800.40	991.85	808.55	12,527.48	1,573.40	771.48	801.92
	11	11,866.61	1,706.23	887.53	818.70	11,842.35	1,568.92	1,135.73	433.19
	12	11,406.15	1,786.80	965.48	821.32	11,340.32	1,608.58	1,175.39	433.19
	13	11,169.47	1,798.30	758.67	1,039.63	10,775.79	1,730.40	927.77	802.63
	14	10,476.36	2,058.64	809.36	1,249.28	10,345.39	1,730.09	1,296.90	433.19
Central	12	26,213.80	3,134.29	1,557.34	1,576.95	26,661.54	2,596.67	2,596.67	0.00
	13	24,931.11	3,004.09	1,404.47	1,599.62	24,499.40	2,689.19	2,689.19	0.00
	14	23,441.61	3,098.02	1,692.00	1,406.02	23,251.14	2,662.57	2,662.57	0.00
	15	22,334.10	3,461.19	1,260.01	2,201.18	22,397.50	2,693.94	2,693.94	0.00
	16	21,482.90	3,499.88	1,237.95	2,261.93	21,355.87	2,718.08	2,718.08	0.00
	17	20,860.29	3,463.26	1,750.03	1,713.23	20,493.68	2,727.14	2,727.14	0.00
	18	19,857.98	3,800.88	1,249.85	2,551.03	19,846.95	2,719.26	2,719.26	0.00
	19	19,367.92	3,614.42	1,800.11	1,814.31	19,135.68	2,766.29	2,766.29	0.00
	20	18,724.80	3,814.82	918.87	2,895.95	18,517.58	2,789.56	2,789.56	0.00
Northeastern	9	37,095.06	1,979.25	807.35	1,171.90	36,368.18	1,422.72	1,422.72	0.00
	10	34,745.96	2,113.59	633.22	1,480.37	34,646.63	1,519.54	1,346.48	173.06
	11	33,372.42	2,131.28	1,269.53	861.75	32,991.71	1,585.99	1,585.99	0.00
	12	32,194.40	1,995.90	954.35	1,041.55	31,814.70	1,666.80	1,666.80	0.00
	13	30,987.88	2,356.98	641.73	1,715.25	30,775.29	1,740.71	832.45	908.26
	14	29,931.89	2,570.78	976.96	1,593.82	29,872.89	1,607.11	0.00	1,607.11
	15	29,018.60	2,763.81	1,384.36	1,379.45	28,828.04	1,649.40	0.00	1,649.40
	16	28,513.12	2,607.55	1,131.61	1,475.94	28,036.60	1,744.23	0.00	1,744.23
	17	27,489.23	2,546.95	1,063.82	1,483.13	27,301.11	1,843.94	1,843.94	0.00
	18	27,122.31	2,581.88	1,826.15	755.73	26,540.57	1,935.33	1,935.33	0.00
	19	26,357.72	2,754.40	2,161.61	592.79	25,939.19	1,967.34	1,586.49	380.85
	20	25,593.88	2,764.76	1,951.78	812.98	25,270.74	2,029.58	2,029.58	0.00

If the location of opened DCs can be changed, then the company needs to make three decisions 1) locating the DCs, 2) allocating DCs to each facility and allocating retailers to each DC, and 3) assigning delivery routes for DCs while minimizing total distance of the system. Then this problem becomes 2E-LRP. In this case a mathematical formulation is constructed. Finding the optimal solutions using exact method is not practical for this large-sized problem. A simple heuristic method is developed to obtain reasonable solutions in a shorter time. It reduces the retailers' distance by 10,432.36 km. or 13.51% and the DCs' distance by 11,338.63 km. or 56.38%. As a result, the total distance of the system is decreased by 21,770.99 km. or about 22.37%. The results suggest that the more DCs opened, the less total distance in the system.

The performance of the proposed method is compared with GA. The results indicate that when number of opened DCs is small, both GA and the proposed method provides similar solutions in the Eastern region. When the number of opened DCs increases, the proposed method yields better solutions. For other region, our method provides shorter total travelling distance. In addition, the proposed method has the shorter computational time. Note that this result of this paper is based on the travelling distance. Further investigation is needed to find the proper number of opened DCs; for example, the costs should be taken into an account.

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