Iranian Journal of Mathematical Sciences and Informatics
Vol. 17, No. 2 (2022), pp 19-44
DOI: 10.52547/ijmsi.17.2.19

Optimizing the Distribution of Dairy Products by Heuristic Algorithms and Geographic Information System: A Case Study of FARS PEGAH DAIRY COMPANY

Meysam Sharifi, Mohammad Bagher Ahmadi*

Department of Mathematics, College of Sciences, Shiraz University, Shiraz, Iran

E-mail: meysamsharifi87@yahoo.com
E-mail: mbahmadi@shirazu.ac.ir

Abstract. The problem of the distribution of dairy products, which is classified as a combinatorial optimization problem, cannot be solved in polynomial time. In this paper, an algorithm based on Ant Colony Hybrid meta-heuristic system and Geographic Information System (GIS) was used to find a near-optimal solution to this problem. Using the former method, the nearest neighbor heuristic algorithm was used to find an initial solution, and then, Campbell insertion algorithm having $O(n^3)$ complexity was applied in order to find a feasible solution. Furthermore, cross exchange local search algorithm was utilized to reduce the time of finding a near-optimal solution. Using the latter method, with regard to geographic features of the problem, the distribution network was optimized by GIS. Besides, we attempted to optimize the distribution network of dairy products using multi-objective mathematical model.

Keywords: Ant colony algorithm, Geographic information system, Vehicle routing problem.

2000 Mathematics subject classification: 90B06, 90B90, 90C27.

*Corresponding Author

Received 19 October 2017; Accepted 15 October 2021

1. Introduction

Given the fact that dairy supply chain includes wide-ranging distribution networks, and logistics and transportation costs of that chain have direct effect on final cost and quality of their product, one of the issues that managers of dairy companies should deal with is deciding on the distribution method of their products. That being so, to reduce the costs and final prices, and to enhance customers' satisfaction and to reach the larger proportion of the market and finally to make the dairy supply chain dynamic, distribution network should be optimized. Due to their short lifetime, dairy products need to be preserved in low temperatures and their transportation requires special vehicles with a freezer. Considering the fact that the capacity of stores for preserving these products is limited, it is essential to reduce the time required for the distribution of dairy products.

In some papers, the coordinate of customers' locations is displayed with two dimensions (x, y) and, instead of calculating real distances between customers' locations, they are illustrated on the basis of a straight line. This approach ignores the complexity of road network and converts matrix distance into direct routes between the two locations. While the exact position in the real world is based on geographic coordinate, finding lighter traffic streets can be a limitation for vehicle routing problem. That being so, this study considers constraints such as the capacity of each vehicle, time needed to give service to each customer, customers' demands, customers' time interval, and the investigation of distribution network in odd and even days. Besides, it takes into account one-way or two-way streets and street hierarchy to cross the routes with lighter traffic by applying GIS based on the shape file of Shiraz city.

This study sought to investigate optimizing the distribution of dairy products through a vehicle routing problem in which a series of constraints were applied in order to approximate to the mathematics modeling regarding the actual problem making it different from the previous related studies including the constraints imposed on the capacity of transportation, the customers physical attendance, and the services provided to each customer. Moreover, the current study intended to reduce the cost of transportation through the application of two-purpose mathematics modeling so as to fostering the least amount of distribution time and the least instruments required. In the first method, the proposed algorithm; double ant colony algorithm was applied in the mathematics model in which the pheromone algorithm and the possibility of the random selection of the ants provide the opportunity of finding the shortest route with which the flexibility in the optimal problem solving will be achieved. In the Customer Graph for instance, if any of the arcs or the customers deleted, there would be no need for the algorithm to solve the problem from the first point, as long as it has the best route from its solution to the deletion of the arcs or the

[DOI: 10.52547/ijmsi.17.2.19]

customer. Since then, the ants can track the optimal route in a short time. On the other hand, what adds to the high generalizability and the self-constructive nature of the algorithm is the searching of the ants without any guidance, the central or the external control. Besides to that, as long as there is no definite behavior on the part of ants, and some of the still go for the longer routs, the system would be able to fit into the environmental change thus, making it suitable for the dynamic environments. This algorithm comprised of the combination of the positive feedback and the distributed computation which prevent fast convergence and trapping ants algorithm on the distributed computation in the optimal points. The positive feedback has the responsibility of recognizing and identifying the appropriate prompt response. The responsibility of the generation of the possible solution of the ants algorithm is on the nearest neighbor heuristic algorithm ; a constructive algorithm with a increasing, step by step method that provides a reasonable solution in the form of a candidate list per each transformation in a way that each customer receives the service. Moreover, the application of this Insertion Heuristic algorithm would lessen the complexity of the time of the problem from $O(n^4)$ to $O(n^3)$ which is in the need of reasonable ways to implement the various replacement methods in incorporating the unregistered customers in the solution. Due to the high speed, the generation of the optimal solution, the simple administration, the flexibility and the adaptability of the option with the various and complicated and problems is highly practical. It is worth noting that the ants algorithm is a constructive one in spite of the itrationable and the use of previous steps along with the movement through the generation of the solution thus, it is in the need of a developmental algorithm in the generation of the appropriate solution. The current study implements a cross exchange heuristic algorithm which is known as one of the best local search algorithms. Practically speaking, the problem of optimal route is the time rather than passed route. Likewise, this point signifies the simulation of different speeds in various routes with the help of the issues including the existing traffic, the slope, etc. although the old models only includes few numbers of constraints related to the problem. The current study made an attempt to consider the constraints such as the one-way or the two-way streets, rotation to either left or right, as well as the constraints on routing and all of the details of the network. The GIS size of the vehicles with the help of the routing and the price of the O-D matrix with regard to the dijkstra algorithm including the solver analysis with the application of tracking the shortest route considering the issue such as the one-way constrain of some routes and the turning, the connection of the streets along with the constraints in the streets.

[DOI: 10.52547/ijmsi.17.2.19]

2. A review of previous research

Dantzig and Ramzer(1959) were pioneers in bringing the idea of routing problem and vehicle transportation into the fore. They suggested a formula and a mathematical algorithm for that [4]. Methods of routing problem and vehicle transportation were categorized into two exact and approximate ones. The routing problem of vehicle transportation subsumed under NP-hard which in response to the increase of the problem, the amount of exact computational methods for the optimal solution have exponential time, thus, the optimal solution of the actual problem with the considerable amount using the exact methods seems impractical. Inevitably, more creative methods must be implemented for the computation of the reasonable solutions and approximate optimal ones [18]. Creative algorithms are categorized into two categories; namely, Approximation Algorithms and the ultra-Approximation Algorithms with the advantage on the latter due to more in depth search in the solution context to find the better optimal solutions as compared to the ones yielded from Approximation Algorithms. Bullnheimer et al., (1997) were the first in implementing the ants algorithm on the routing problem [1]. In continuation to their endeavor, Gambrdella and Taillard (1999) investigated the vehicle routing problem with time window using the ants algorithm [8]. Additionally, Zhang and Tang, (2008) used the ultra-Approximation Algorithms of the colony of ants algorithm in the scattered search for the vehicle routing problem with time window [20]. One of the other common estimating algorithm which in combination with the ants algorithm generates optimal and efficient solutions is the insertion algorithm which was first presented by Solomon(1987) [15]. It was proposed in line with the Cheapest Insertion. In addition, Campbell and Savelsbergh (2004) proposed the insertion algorithm in which the time complexity was reduced from $O(n^4)$ to $O(n^3)$ [2]. Along with the same line of research, Ding, Hu, Sun and Wan (2012) make the use of ants algorithm that a candidate list is adopted by ants to move to the next client with the list being one quarter of the whole population of the customers. What arranges the customers is the distance where the nearest customers stand according to that to select the next customer among the list or through the transformation of them [5]. He vehicle routing problem is matter of geographical issue, thus GIS, which was introduced in the US [9], for the first time in 1992 and registered as a database of articles, is a great help in making a better decision [14]. During the decades ago, GIS has been recognized and used as an efficient tool in a wide range of programs including the smart transformation programming and management as well as the management of the guiding path system for the research modeling [17]. and the decision making procedures leading to the approach of GIS for Transportation [7]. To find the shortest route, Dijkstra algorithm is used [3], which was primarily presented by Whiting and Hiller (1959) [6]. This

[DOI: 10.52547/ijmsi.17.2.19]

algorithm concerns with finding the route between the customers as well as finding the shortest route from the first to the other customers.

3. Mathematical model

The problem has been defined on the directed graph $G = (V, A)$. In this graph, nodes $\{1, 2, ..., n\}$ are the customers and depot is represented by 0 and $n + 1$. All the truck paths start from node 0 and end in node $n + 1$. Besides, $A = \{(i, j); i \neq j\}$ is the set of all the arcs. Variables and parameters which are used in the model are as follows:

b_i: is the earliest time service for customer i

e_i: is the latest time service for customer i

B: is the earliest departure time from the depot

E: is the latest return time to the depot

s_i: is the longtime service for customer i

W_i^k: is the starting time to get service to customer i by vehicle k

q_i: is the demand for customer i

Q: is the capacity of each vehicle

DQ: is the amount of goods in the depot

$t_{i,j}$: is the traveling time from customer i to customer j

K: is the collection of all vehicles so that $K = \{1, 2, ..., k\}$

N: is the collection of the networking nods (customers and depot)

$\Delta^+(i)$: is the set of all customers to whom we can travel from customer i (customers j so that $(i, j) \in A$)

$\Delta^-(i)$: is the set of all customers from whom we can travel to customer i (customers j so that $(j, i) \in A$)

$$X_{ij}^k = \begin{cases} 1, & \text{if } vehicle\, k\, immediately\, meets\, customer\, j\, after\, customer\, i \\ 0, & \text{otherwise} \end{cases}$$

According to the defined variables and parameters, the mathematical model is as follows:

$$\min \sum_{k \in K} \sum_{(i,j) \in A} t_{ij} x_{ij}^k, \tag{3.1}$$

$$\min \sum_{k \in K} \sum_{j \in \Delta^+(0)} x_{0j}^k, \tag{3.2}$$

s.t.

$$\sum_{j \in \Delta^+(0)} x_{0j}^k = 1, \quad \forall k \in K, \tag{3.3}$$

$$\sum_{i\in\Delta^-(n+1)} x^k_{i(n+1)} = 1, \quad \forall k \in K, \tag{3.4}$$

$$\sum_{k\in K}\sum_{j\in\Delta^+(i)} x^k_{ij} = 1, \quad \forall i \in N, \tag{3.5}$$

$$\sum_{i\in\Delta^-(j)} x^k_{ij} - \sum_{i\in\Delta^+(j)} x^k_{ji} = 0, \quad \forall k \in K, j \in N, \tag{3.6}$$

$$\sum_{i\in N}\sum_{j\in\Delta^+(i)} q_j x^k_{ij} \le Q, \quad \forall k \in K, \tag{3.7}$$

$$\sum_{k\in K}\sum_{(i,j)\in A} q_i x^k_{ij} \le DQ, \tag{3.8}$$

$$\sum_{k\in K}\sum_{j\in\Delta^+(0)} x^k_{0j} \le K, \quad \forall k \in K, \tag{3.9}$$

$$w^k_i + s_i + t_{ij} - w^k_j \le (1 - x^k_{ij}) max(e_i + s_i + t_{ij} - b_j, 0), \quad \forall k \in K, (i,j) \in A, \tag{3.10}$$

$$b_i \sum_{j\in\Delta^+(i)} x^k_{ij} \le w^k_i \le e_i \sum_{j\in\Delta^+(i)} x^k_{ij}, \quad \forall k \in K, i \in N, \tag{3.11}$$

$$B \le w^k_i \le E, \quad \forall k \in K, i \in \{0, n+1\}, \tag{3.12}$$

$$\sum_{(i,j)\in A} x^k_{ij}(w^k_i + s_i + t_{ij}) \le E, \quad \forall k \in K, \tag{3.13}$$

$$x^k_{ij} \ge 0, \quad \forall k \in K, (i,j) \in A \tag{3.14}$$

$$x^k_{ij} \in \{0,1\}, \quad \forall k \in K, (i,j) \in A \tag{3.15}$$

Relations (3.1) and (3.2) represent the first and second objective functions that minimize the total time and the number of vehicles for the distribution of dairy products, respectively. Constraint (3.3) ensures that each vehicle must start to move from the depot node and select only one customer to go from the depot to the next node. Constraint (3.4) represents that all the vehicles must return to the depot. Constraint (3.5) shows that each customer must be served only once and also only by one vehicle. Constraint (3.6) shows that if a vehicle enters the customer node, must get out of it. Constraint (3.7) states that total customer demands in each route must not exceed the capacity of any vehicle. Constraint (3.8) ensures that total customer demands must not exceed the total number of products in the depot. Constraint (3.9) ensures that the number of vehicles out of the depot should not be more than that of vehicles in it. Constraint (3.10) states that service to customer j must be after service

[DOI: 10.52547/ijmsi.17.2.19]

to customer i. Constraint (3.11) ensures that starting time of the service to each customer must be in the specific time window belonging to that customer. Constraint (3.12) shows that starting time of the service to each customer must be within the time window of the total distribution network. Constraint (3.13) states that the maximum time that any vehicle can travel along the path should be less than or equal to the latest return time. Constraints (3.14) and (3.15) ensure that the solution is positive and correct.

4. Suggested algorithm

Considering the fact that the issue under consideration, i.e., solving a combined optimization problem by exact mathematical methods, is very complicated, to optimize the model of distribution of dairy products, the Double Ant Colony System heuristic algorithm is used. In this algorithm, we apply two different ant colonies $ACS-VEHI$ to decrease the number of vehicles and $ACS-TIME$ to reduce the service time to customers. This algorithm relies on the initial solution that is created by the Nearest Heuristic Algorithm from which the number of needed vehicles ($active\,vehicles$), routes network (ψ_{gb}) and total time required to provide all customers (ϕ_{gb}) with services result.

Then, we activate ant colonies, and compare the newly obtained solution from each colony to the previous ones. If we get a better solution from colonies, we will use the new solution instead. Colonies interact with each other through using the same network of traveled paths ψ_{gb}. $ACS-VEHI$ colony has attempted to apply one less vehicle to give service to all customers, which means fewer vehicles than the initial ones, and $ACS-TIME$ colony has tried to get answers with less time needed with the same number of available vehicles. Then, the answers are compared with the best solution obtained from the suggested algorithm, and if this answer is better than that one, it will be stored as the optimized solution. This cycle will continue up to the point in which the number of solution creation by ants becomes twice as many as that of customers [11].

In this article, the nearest neighborhood heuristic algorithm starts with one vehicle from the depot, explains two variables, $Current\,Time$ and $current\,load$, and calculates $candidate\,list$.

Variable $Current\,Time$, which starts from the time zero and travels from one customer to another one, is updated as follows:

$$A_j = Current\,Time_{jv} + t_{ij}, \tag{4.1}$$

$$Current\,Time_{jv} = \begin{cases} A_j + S_j, & \mathrm{A}_j < b_j \\ b_j + S_j, & \mathrm{A}_j \geq b_j \end{cases} \tag{4.2}$$

[DOI: 10.52547/ijmsi.17.2.19]

where t_{ij} is the time interval between customer i and customer j, index v is related to vehicle, s_j is the length of time giving service to customer j, and b_j is the beginning of customer j's time window.

Algorithm 4.1. *Suggested algorithm*

Step1

1.1. *Creating an initial answer by the closest neighbor heuristic algorithm*

1.2. *Storing the number of vehicles which are needed for giving service to all customers* (v) *at "active vehicles" variable*

1.3. *Saving created graph at* ψ_{gb}

1.4. *Storing the total time at variable* ϕ_{gb}

Step2

2.1. *Activating* $ACS-VEI(v-1)$ *colony*

2.2. *Activating* $ACS-TIME(v)$ *colony*

Step3

3.1. *Updating variables* ψ_{gb} *and* ϕ_{gb} *in order to find a better answer than the initial answers in these two variables.*

Step4

4.1. *constructing new colonies in case the number of vehicles in the new solution becomes fewer than that of definite vehicles in variable "active vehicles" and updating variable "active vehicles"*

Step5

5.1. *Repeating steps 2 to 4 until the conditions are met.*

Variable $Current\,Load$ also starts from time zero, and is updated by traveling from one customer to another as follows:

$$Current\,Load_{jv} = Current\,Load_{jv} + q_j, \tag{4.3}$$

where q_j is the demand of customer j.

$Candidate\,List$ includes all the customers who have received no service yet. It has some conditions which are as follows:

$$Current\,Time_{jv} + t_{ij} \leq e_j, \tag{4.4}$$

$$Q - Current\,Time_{jv} + t_{ij} \geq q_j, \tag{4.5}$$

Q is the capacity of each vehicle and e_j is the end of customer j's time window.

In $ACS-VEI$ colony, we aim at giving service to all customers considering the number of vehicles in variable S which is defined as $S = active\,vehicles - 1$.

Colony $ACS-VEI$ stores the number of customers who receive service by S vehicles in variable $\psi_{ACS-VEI}$. At first, the value of variable $\psi_{ACS-VEI}$ equals to the result obtained from S vehicles made by the nearest heuristic algorithm ($\psi_{ACS-VEI}$ is not necessarily feasible). Then, ants produce the solution with the application of Ant colony system process and the number of customers who have got the service will be calculated and stored in variable ψ^k. if $\psi^k \geq \psi_{ACS-VEI}$, then, $\psi_{ACS-VEI}$ variable will be updated. If the number of all customers equals to $\psi_{ACS-VEI}$, then, the answer will be sent to the suggested algorithm and variables, $active\,vehicles$, ψ_{gb} and ϕ_{gb} will be updated and two new colonies with value of $ACS-VEI(S-1)$ and $ACS-TIME(S)$ will start working. Next, the global updating Pheromone will be done on the produced solution as follows:

$$\tau_{ij} = (1-\rho)\tau_{ij} + \frac{\rho}{\Gamma\psi_{ACS-VEI}}, \quad \forall(i,j) \in \psi_{ACS-VEI}, \tag{4.6}$$

in which ρ is Pheromone evaporation factor, and Γ is the length of the best route up to now, and $\psi_{ACS-VEI}$ is the number of customers met in $ACS-VEI$ colony.

In colony $ACS-TIME$, the goal is to find a path with less time and fewer number of vehicles stored in variable $active\,vehicles$. In this colony, m ant begins to produce a solution by applying the process to find solutions.

If the number of vehicles is not fewer than or equal to variable $active\,vehicles$, then, the algorithm will enter the insertion step. Afterward, if the produced solution by an ant is feasible (it means it visited all the customers), then, we will use the local search algorithm to optimize the solution. In the following, if the produced solutions are better than the stored ones in variable ϕ_{gb}, then, the produced solutions will be sent to the suggested algorithm and variables ϕ_{gb} and ψ_{gb} will be updated. Pheromone global updating is as follows:

$$\tau_{ij} = (1-\rho)\tau_{ij} + \frac{\rho}{\Gamma\,\psi_{gb}}, \quad \forall(i,j) \in \psi_{gb}, \tag{4.7}$$

In colonies $ACS-VEI$ and $ACS-TIME$, each ant uses the process to produce a solution so that each of them calculates the candidate list while they are traveling from one customer to another. Then, they calculate the heuristic information and also the Pheromone while they are traveling from customer i to customer j as follows:

$$Delivery\,Time_j \longleftarrow Max(Current\,Time_i + t_{ij}, b_j) \tag{4.8}$$

[DOI: 10.52547/ijmsi.17.2.19]

$$Distance_{ij} \longleftarrow Delivery\,Time_j - Current\,Time_i \tag{4.9}$$

$$Distance_{ij} \longleftarrow Max(1, Distance_{ij} - IN_j) \tag{4.10}$$

$$\eta_{ij} \longleftarrow \frac{1}{Distance_{ij}} \tag{4.11}$$

Formula for local updating:

$$\tau_{ij} \longleftarrow (1-\rho)\tau_{ij} + \rho\,\tau_0 \tag{4.12}$$

In the first iteration:

$$\tau_0 = \frac{1}{n \times \Gamma\,\psi_{gb}}$$

And we consider $IN_j = 0$. Considering the number of times a customer has not been in an ant's solution in the previous iteration of the algorithm (IN_j), it makes that customer j with higher priority than other customers who received the service in the previous iteration enters a new solution to the problem. Then, one algorithm by using the probability law and two mechanisms of Exploration and Exploitation, selects the next customer as follows:

If $q \le q_0$, then, customer j is selected in such a way that it has the highest value as the following (exploitation):

$$P_{ij} = \begin{cases} \dfrac{\tau_{ij}[\eta_{ij}]^\beta}{\sum_{i \in N_j^k} \tau_{il}[\eta_{il}]^\beta}, & \forall j \in N_j^k \\ 0, & \text{otherwise} \end{cases}$$

Where β is the parameter which specifies the importance of pheromone against the distance between customers, q is the random number with the uniform distribution in the interval of $[0,1]$, and q_0 is the parameter in the interval of $[0,1]$ that shows the relative importance of mechanism Exploitation against Exploration. The smaller the amount of q_0 is, the less the probability of using the Exploitation mechanism over Exploration mechanism will be. After choosing the next customer for receiving service by the probability law, the traveled path (the number of customers who got service) so far (ψ^k), $Current\,Time_k$ and $Current\,Load_k$ and the amount of local pheromone (τ_{ij}) are updated as follows:

$$\psi_k \longleftarrow \psi_k + j, \tag{4.13}$$

$$Current\,Time_k \longleftarrow Delivery\,Time_j + s_j, \tag{4.14}$$

$$Current\,Load_k \longleftarrow Current\,Load_k + q_j, \tag{4.15}$$

[DOI: 10.52547/ijmsi.17.2.19]

$$\tau_{ij} \longleftarrow (1-\rho)\tau_{ij} + \rho\,\tau_0, \tag{4.16}$$

If $j = 0$ (depot), then:

$$Current\,Time_k \longleftarrow 0, \tag{4.17}$$

$$Current\,Load_k \longleftarrow 0, \tag{4.18}$$

The operation will be continued until the *candidate list* empty. Afterwards, variable IN_j is updated. At this stage, the solution of the problem is created by ant k ; however, there may have been some customers who did not obey the limitations of the time window as well as the capacity of the vehicle so that they do not enter the solution generated by each ant; therefore, we apply Insertion Heuristic Algorithm.

In this article, we use Insertion Heuristic Algorithm that was developed by Campbell and Savelsbergh in 2003. For every customer j who has not entered the solution, this algorithm begins to evaluate the entering of customer j between customers $i-1$ and i, and starts the insertion from depot and after inserting customer j among all customers, it finally comes back to the depot.

For every customer j who is ready to join the solution, we have to calculate B_j and E_j (the earliest and the latest time that customer j can receive the service) as following:

$$[B_j, E_j] \subseteq [b_j, e_j]$$

$$B_j = Max(b_j, B_{i-1} + s_{i-1} + t_{i-1,j}) \tag{4.19}$$

$$E_j = Min(e_j, E_i - s_i - t_{ji}) \tag{4.20}$$

In the first iteration, there will be $B_{i-1} = b_{i-1}$ and $E_i = e_i$. Customer $i-1$ and i will be candidates for the insertion of customer j provided that the constraint of time window and the vehicle capacity would be calculated as follows:

$$B_j \leq E_j, \tag{4.21}$$

$$q_j \leq Q - Load_{r_i}^{\psi^k}. \tag{4.22}$$

Where Q is the vehicle capacity, and $Load_{r_i}^{\psi^k}$ is the total amount of customers' demands (customers i), which is the created path by ant k. If in one route, there are more than one pair of customer candidates for being inserted in node j, then, a cost function is applied as follows such that the pair of customers which have the lowest cost can be selected.

[DOI: 10.52547/ijmsi.17.2.19]

$$C[i-1(j), j, i(j)] = t_{i-1,j} + t_{ji} - t_{i-1,i}, \tag{4.23}$$

After choosing the best pair of customers and inserting customer j, vehicle capacity and the earliest time to get service to the customers located after customer j and the latest time to get service to the customers located before customer j will be updated as follows:

$$B_k = Max(B_k, B_{k-1} + s_{k-1} + t_{k-1,k}), \tag{4.24}$$

$$E_k = Min(E_k, E_{k+1} - s_k - t_{k,k+1}) \tag{4.25}$$

$$Load_{r_i}^{\psi^k} \longleftarrow Load_{r_i}^{\psi^k} + q_j, \tag{4.26}$$

Since the ant colony algorithm is a constructive algorithm, it needs the recovery algorithm to establish an appropriate solution. In this article, after making a feasible solution by each ant in the $ACS-TIME$ colony, the Local Search Cross-Exchange Algorithm is implemented on the solutions whose lengths are between 60 to 90 percent of the best route. Two routes are randomly selected; then, some sequential customers of one route are exchanged with other customers of another route in such a way that it does not change the direction. For this purpose, the first and the last customers of any route will not be in this process. After the exchange, if the constraint vehicle capacity does not violate for two new routes, that is, if the constraint vehicle capacity for two new routes r_i and r_{i+1} is as follows:

$$Current\, Load_{r_i} = q_{i-1} + \sum_{m=i}^{k} q_m + q_{k+1}, \tag{4.27}$$

$$Current\, Load_{r_{i+1}} = q_{j-1} + \sum_{m=j}^{l} q_m + q_{l+1}, \tag{4.28}$$

After the exchange, it must be:

$$Current\, Load_{r_i} = q_{i-1} + \sum_{m=l}^{l} q_m + q_{k+1} \leq Q, \tag{4.29}$$

$$Current\, Load_{r_{i+1}} = q_{j-1} + \sum_{m=i}^{k} q_m + q_{l+1} \leq Q, \tag{4.30}$$

We have to investigate whether the optimum solution (further reduction of total time) is established through this procedure or not. To this aim, the $Saving$ variable is defined as follows:

$$Saving = TLAI - TLPI, \tag{4.31}$$

[DOI: 10.52547/ijmsi.17.2.19]

In this formula, $TLPI$ is the time needed for giving service to the customers of two routes before the exchange, and $TLAI$ is the time needed for giving service to the customers after that, as follows:

$$TLPI = t_{(i-1,i)} + \sum_{m=i}^{k} t_{(m,m+1)} + t_{(k,k+1)} + t_{(j-1,j)} + \sum_{m=j}^{l} t_{(m,m+1)} + t_{(l,l+1)} + \sum s_i, \tag{4.32}$$

$$TLAI = t_{(i-1,j)} + \sum_{m=j}^{l} t_{(m,m+1)} + t_{(l,k+1)} + t_{(j-1,i)} + \sum_{m=i}^{k} t_{(m,m+1)} + t_{(k,l+1)} + \sum s_i, \tag{4.33}$$

where $\sum s_i$ is the total time service to all customers of the two selected paths. If variable $Saving$ is negative, it means that the length of time path after the exchange will be less than its length before it. In this case, we have to calculate B_j and E_j for all customers of the new routes after the exchange. If $B_j \leq E_j$ is satisfied for all customers of both paths, then, the, exchange will be accepted, and vehicle capacity and customers' time window will be updated as follows [11]:

$$B_k = Max(B_k, B_{k-1} + s_{k-1} + t_{k-1,k}), \tag{4.34}$$

$$E_k = Min(E_k, E_{k+1} - s_k - t_{k,k+1}), \tag{4.35}$$

$$Current\, Load_{r_i} = q_{i-1} + \sum_{m=j}^{l} q_m + q_{k+1} \leq Q, \tag{4.36}$$

$$Current\, Load_{r_{i+1}} = q_{j-1} + \sum_{m=i}^{k} q_m + q_{l+1} \leq Q, \tag{4.37}$$

5. Problem Data

In this study, we collected data from region 4 of Fars Pegah Company that included 8 trucks and 181 customers. Each truck could transport at least 1400 kilogram of dairy products and give service to all customers between 6 a.m. till 2 p.m. We could estimate the speed of each truck which turned out to be 45 kilometers per an hour. We met all shopkeepers directly and collected information about time window constraints and service time to each customer (in terms of minutes) as well as more data about customers' location with geographical coordinates by using GPS. Moreover, we assembled the information about the rate of customers' demands in terms of Kg based on the average purchase in 3 months, January, February, and March in 2015 in Fars Pegah

[DOI: 10.52547/ijmsi.17.2.19]

Company. Customer service were daily or odd or even days, that is, 60 customers were on even days according to the table 1, 59 customers were on odd days according to the table 2 and 62 customers were daily.

$Routenumber$	$Numberofcustomers$	$Routedemand(kg)$	$Lengthoftime(m)$
1	12	1000	400
2	22	1100	460
3	19	1100	450
4	12	1000	300
5	19	1050	360
6	10	1000	330
7	17	900	480
8	10	800	450

Table 1. Initial routes of Fars Pegah Company on even days.

$Routenumber$	$Numberofcustomers$	$Routedemand(kg)$	$Lengthoftime(m)$
1	12	1000	400
2	20	1100	450
3	18	1100	450
4	13	1000	320
5	19	1050	360
6	15	1000	380
7	16	900	480
8	8	800	420

Table 2. Initial routes of Fars Pegah Company on odd days.

6. Implementation of suggested algorithm

We achieve distance matrix 182×182 asymmetric entry which shows the length of time among all customers and the depot by using Geographic Information System, and we are coding the algorithm mentioned earlier through programming MATLAB R2012a. The algorithm applies ten ants for both two colonies, and each colony repeats 400 times. The needed parameters to solve the problem are defined as follows:

$m = 10$ (the number of ants), $q_0 = 0.9$ (the parameter which is used in probability law), $\beta = 2$ (the parameter which is used in probability law), $\rho = 0.1$ (level of evaporation)

[DOI: 10.52547/ijmsi.17.2.19]

$Routenumber$	$Numberofcustomers$	$Routedemand(kg)$	$Lengthoftime(m)$
1	17	1028.85	316
2	23	1387.7	369
3	22	1394.66	328
4	23	1388.91	381
5	17	1382.1	359
6	19	1395.13	282

Table 3. The optimized routes by suggested algorithm on even days.

$Routenumber$	$Numberofcustomers$	$Routedemand(kg)$	$Lengthoftime(m)$
1	24	1393.31	330
2	33	1387.19	436
3	15	1396.56	278
4	21	1395.83	407
5	6	564.05	143
6	22	1399.98	368

Table 4. The optimized routes by suggested algorithm on odd days.

The optimized routes by suggested algorithm on even days according to table 3 on odd days according to table 4.

The results of the algorithm show 25 percent reduction in the number of trucks in comparison with initial routes of the company. Besides, the length of time of distribution of dairy products decreases 39.82 percent on odd days and 37 percent on even days based on the suggested algorithm.

7. Solving the problem by GIS

To solve the problem, at first, information and data on the updated map gained from the municipality of Shiraz were implemented and the shape file output was generated which included the shape file of the road network of Shiraz as well as that of customers' information defined as input for ArcGIS 102.2 according to the graphical figure 3. Secondly, a database was established in a gdb and the two shape files were entered as inputs of the database in a feature data set which was located in the geographical database. Next, a network data set was made through which some features for the network such as one-way roads, the hierarchy of roads, time, meters and minutes as value or cost were defined. Then, information in Arc Map was loaded and we began to solve the problem by using feature network analyst. The answers to the

[DOI: 10.52547/ijmsi.17.2.19]

problem are expressed in the graphical figure 1 on even days and the graphical figure 2 on odd days and in the table 5 on even days and in the table 6 on odd days.

$Routenumber$	$Numberofcustomers$	$Routedemand(kg)$	$Lengthoftime(m)$
1	7	1028.45	149
2	22	1359.78	348
3	21	1396.52	328
4	22	1396.57	399
5	27	1398.7	480
6	22	1397.33	432

Table 5. The optimized routes by GIS on even days.

$Routenumber$	$Numberofcustomers$	$Routedemand(kg)$	$Lengthoftime(m)$
1	4	576.21	98
2	20	1398.04	346
3	24	1396.03	391
4	21	1377.46	355
5	28	1394.78	452
6	24	1394.43	443

Table 6. The optimized routes by GIS on odd days.

The results from GIS show 25 percent reduction in the number of trucks needed for giving service to all customers compared with initial routes of Fars Pegah Company. Moreover, the distribution time of dairy products decreased 36.05 percent on odd days and 33.87 percent on even days based on the suggested algorithm.

Considering the Optimizing the distribution of dairy products is a combinatorial optimization problem, such as non- deterministic polynomial- hard, there seems that if the number of the customers increases, exact algorithms would not be able to solve the problem. The only solution would entail skipping the optimization at the cost of efficiency. In other words, with the help of meta heuristic algorithms, the closest solution to the optimal solution would be found. Accordingly, the VRPTWS mathematical model is defined with two objective functions purposing the reduction of the transformation vehicles and the minimizing the distribution time of each vehicle with a series of constraints along the approaching of the model to the actual problem. What makes the current study different from those of its kind is the consideration of

[DOI: 10.52547/ijmsi.17.2.19]

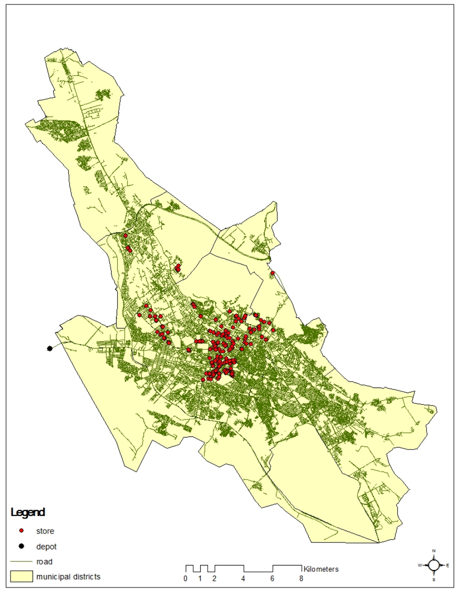


FIGURE 1. Distribution zone of dairy products of FARS PEGAH DAIRY COMPANY.

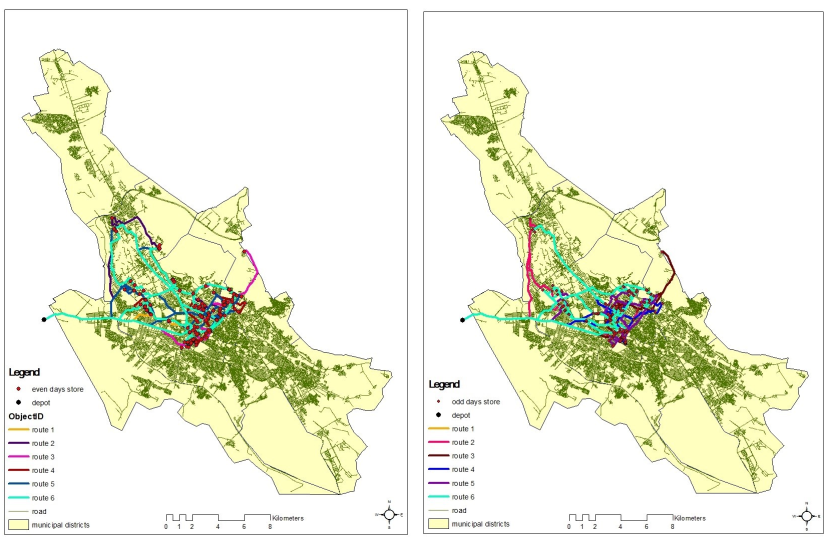


FIGURE 2. The optimized routes by GIS on even (left) and odd (right) days.

time constraints, and the vehicle capacity, the constraint of the service time to customers. In the same line, in order to achieve the optimal solutions in the mathematical VRPTWS model, two methods were implemented focusing

[DOI: 10.52547/ijmsi.17.2.19]

on the data from the Pegah Company; one of the most well-known dairy producers in Iran, which provides the best service to the customers in this regard. In the first method, the input data were assessed using the nearest neighbor heuristic algorithm, followed by the location of the tentative solutions in the selected list according to the DACS and VRPTWS which concerned with the two colonies of ACS-VEI and ACS-TIME with the purpose of minimizing the distribution time of each vehicle and the number of them respectively. Then, through the insertion algorithm and the repeated replacement along with the consideration of the constraints of the problem, attempts were made to enter the customers who were not included in the solution to problem so far. Considering the repeated nature of the ants algorithm in response to the generation of the optimal solution, cross exchange heuristic algorithm on the routs constructed by ants in the colony of ACS-TIME was implemented. In the second method, the network of dairy distribution network by the help of GIS through shape file of Shiraz City and the constraints such as one way streets, the existing traffic and various speed with regard to the slope of the routs and the streets using the Arc Map software optimized with the Network Analyst with which the analyzer Solver network was used according to Dijkstra. Finally, the results of both methods were assessed.

Corollary 7.1. *In this study, we compared the results obtained from the suggested algorithm and GIS and company's initial routes in order to test and assess the validity of the suggested algorithm. Findings of the study pointed out that the results from the suggested algorithm were much more satisfactory than those of the initial routes defined by the company, and also they were a bit more satisfactory than the results from GIS.*

Acknowledgments

The authors wish to thank the referees for their valuable comments which helped to improve the paper.

References

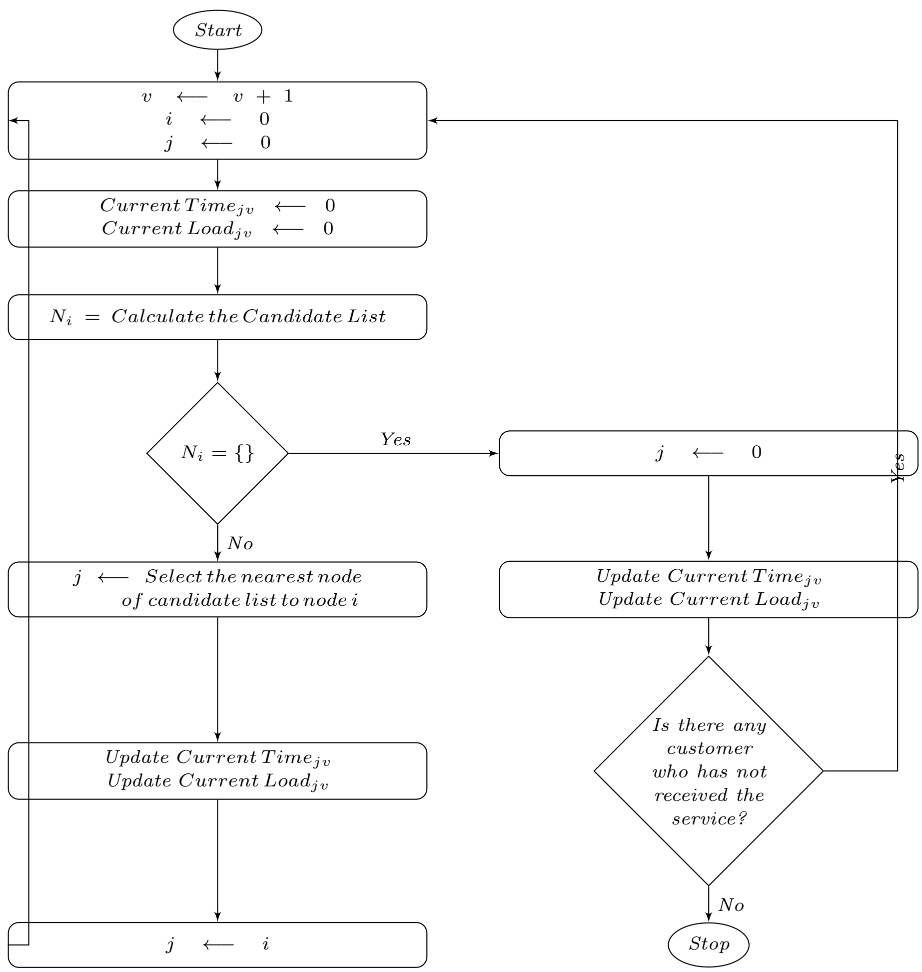
1. B. Bullnheimer, R. F. Hartl, C. Strauss, Applying the Ant System to the Vehicle Routing Problem, Paper presented at Second International Conference on Metaheuristics, Sophia-Antipolis, France, 1997.
2. A. campbell, M. Savelsbergh, Efficient Insertion Heuristic For Vehicle Routing And Scheduling Problems, *Transportation science*, **38**(3), (2004), 369-378.
3. T. Cormen, C. leiserson, R. Rivest, *introduction to algorithm*, MIT Press, 1990.
4. G. Dantzig, J. Ramser, The Truck Dispatching Problem, *Management Science*, **6**(1), (1959), 80-91.
5. Q. Ding, X. Hu, L. Sun, Y. Wang, An Improved ant Colony Optimization and Its Application to Vehicle Routing Problem with Time Windows, *Neurocomputing*, **98**, (2012), 101-107.
6. E. Dijkstra, *A Note on Two Problems in Connection with Graphs*, **1**, 1959, 269-271.

7. D. Fletcher, *Geographic Information Systems for Transportation*, 2000.
8. L. M. Gambardella, E. Taillard, G. Agazzi, MACS-VRPTW: A Multiple Ant colony System for Vehicle Routing Problem with Time Windows, *Technical Report*, IDSIA-06-99, Lugano, Switzerland, (1994), 1276-1290.
9. M. Goodchild, *Geographial Information Science*, **6**, 31-45, 1992.
10. C. Hsu, H. Li, Vehicle Routing Problem with Time Windows for Perishable Food Delivery,*Journal of Food Engineering*, **80**, (2007), 465-475.
11. S. Krichen, S. Faiz, T. Tlili, K. Tej, Tabu-based GIS for Solving the Vehicle Routing Problem, *Expert Systems With Applications*, (2014), 1-11.
12. L. Mao, The Geography, Structure, and Evolution other GIS Research Community in the US: Network Analysis from 1992 to 2011, Transactions in GIS, n/a-n/a.
13. A. Osvald, L. Stirn, A Vehicle Routing Algorithm for the Distribution of Fresh Vegetables and Similar Perishable Food,*J Food Eng*, **85**(2), (2008), 285-295.
14. A. Seine, *Rapport Sur la Marche ET les Effects du Cholera*, 1832.
15. M. Solomon, Algorithms for the Vehicle Routing and Scheduling Problems with Time Window Constraints, (35), (1987), 254-265.
16. C. D. Tarantilis, C. T. Kiranoudis, Metaheuristic Algorithm for the Efficient Distribution of Perishable Foods,*Journal of Food Engineering*, **50**, (2001), 1-9.
17. J. Thill, Geographic information systems for transportation in perspective, **8**(6), (2000), 3-12.
18. P. Toth, D. Vigo, *The Vehicle Routing Problem*, SIAM monographs on discrete mathematics and application, 2002.
19. C. Zabala, J. Torres, Implementation of an Ant Colony System with Local Search for the Vehicle Routing Problem with Capacity and Time Windows (CVRPTW), Third International Conference on Production Research, Americas Region, 2006.
20. X. Zhang, L. Tang, A New Hybrid ant Colony Optimization Algorithm for the Vehicle Routing Problem, (30), (2008), 848-855.

[DOI: 10.52547/ijmsi.17.2.19]

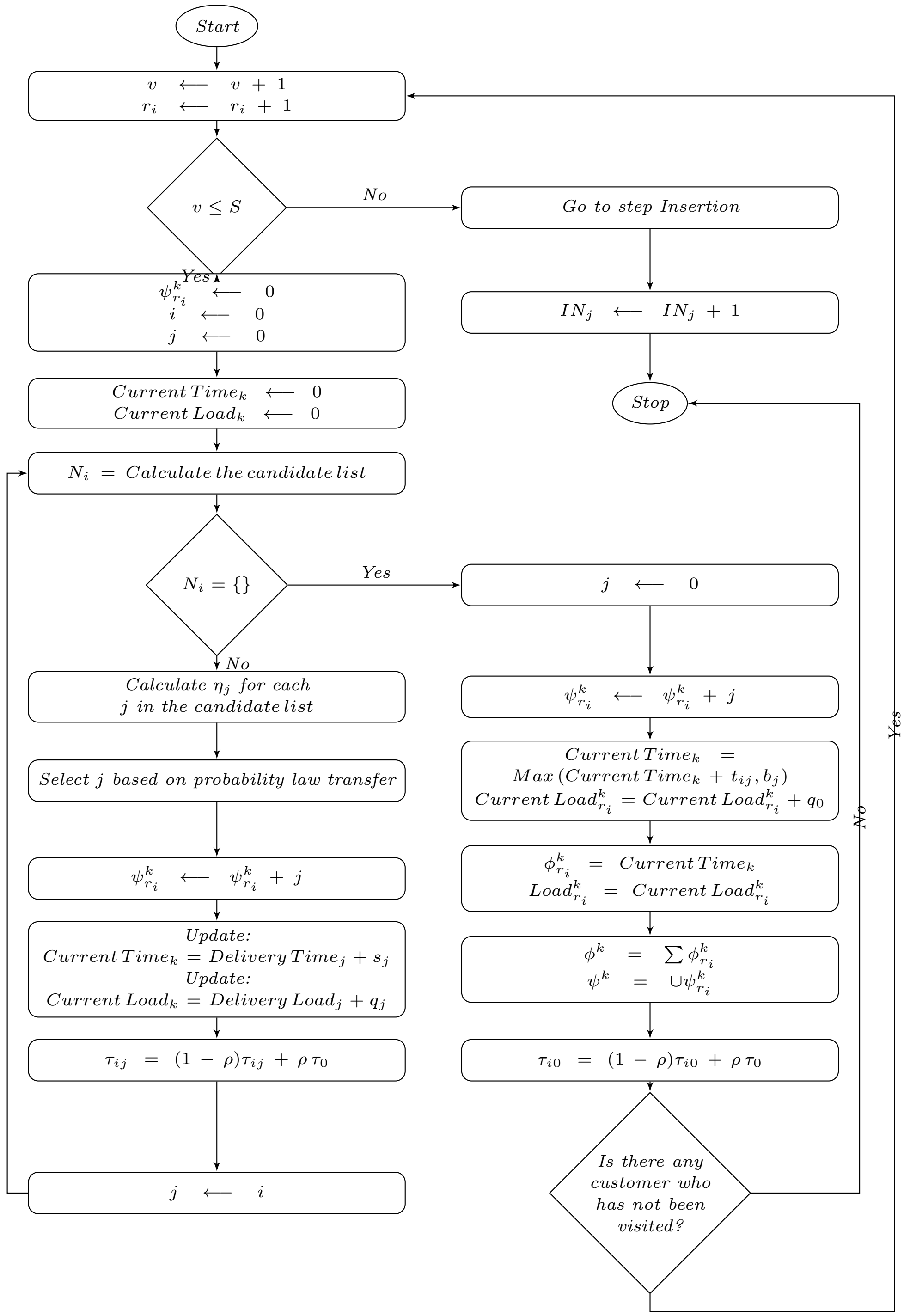
8. Flowcharts of the suggested algorithm

Algorithm 8.1. *neighborhood heuristic algorithm*



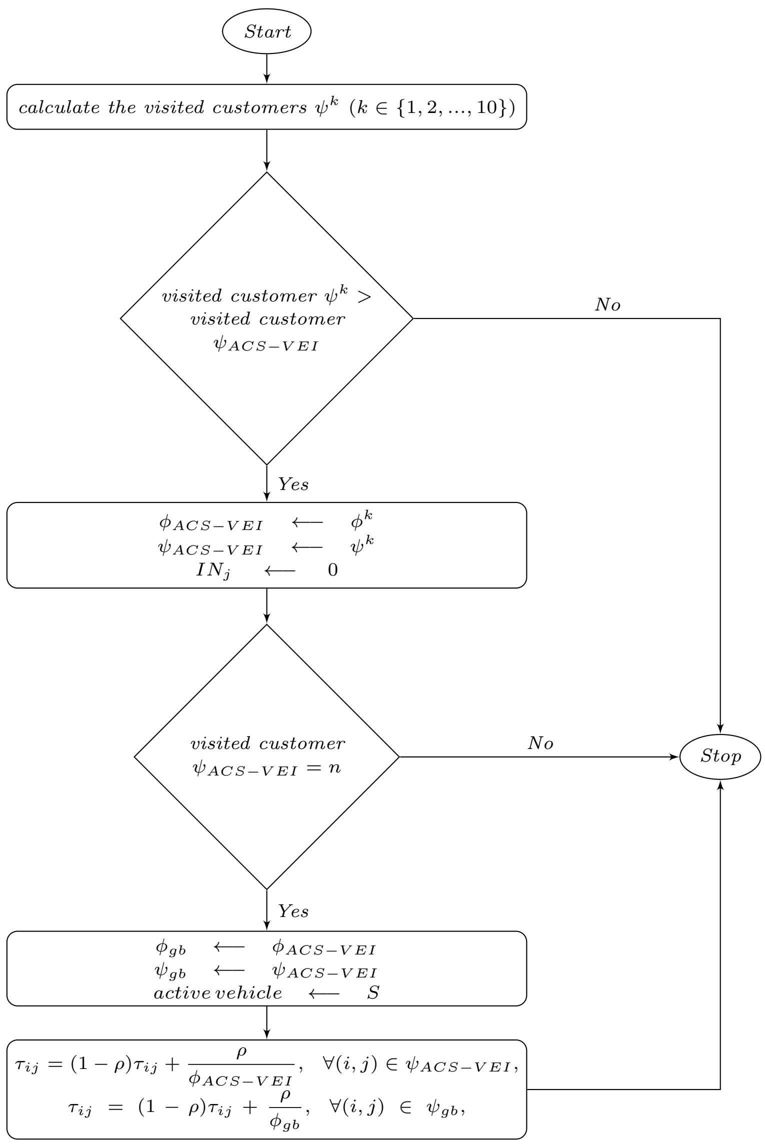
[DOI: 10.52547/ijmsi.17.2.19]

Algorithm 8.2. *ACS-VEI algorithm for one ant*



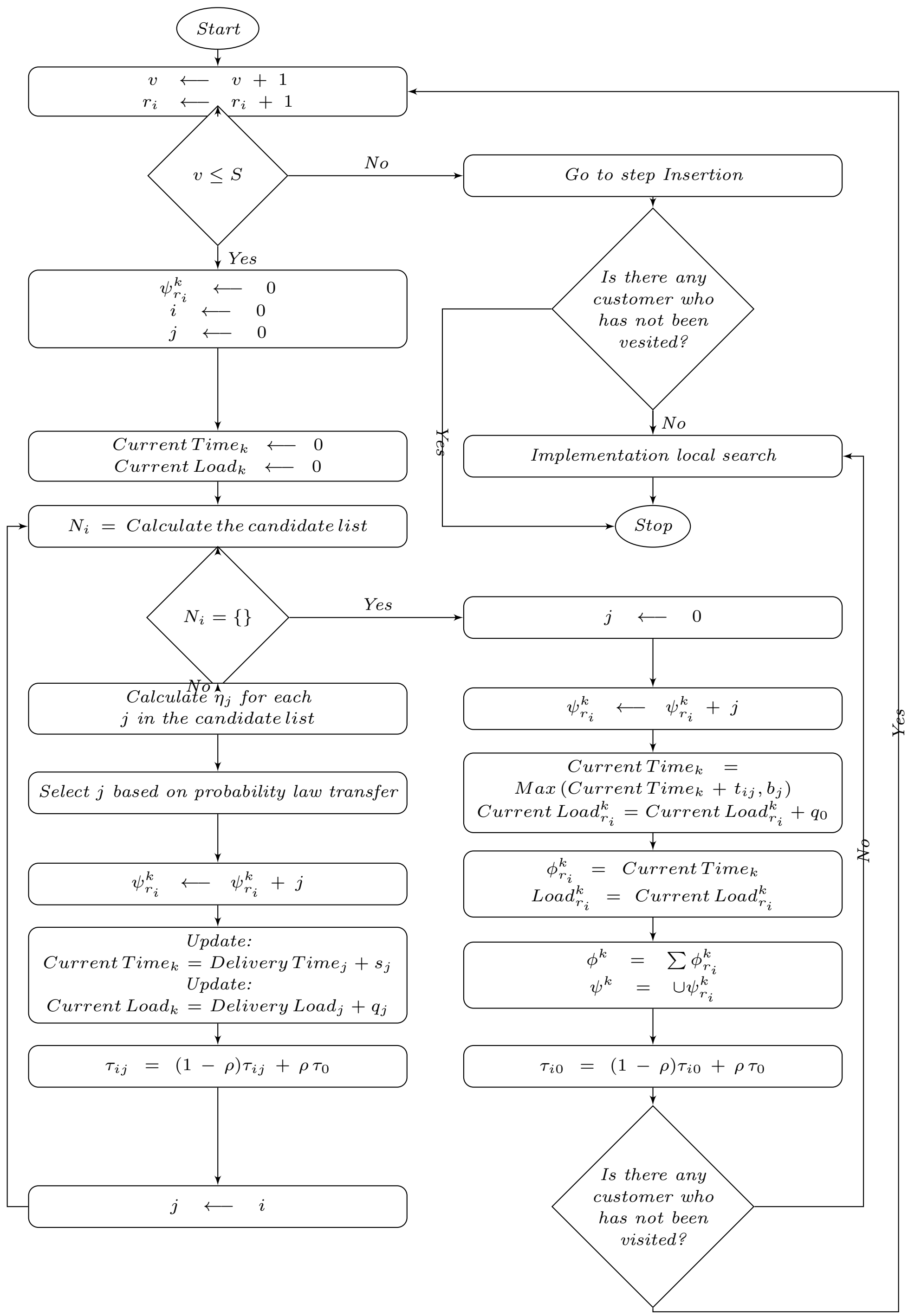
[DOI: 10.52547/ijmsi.17.2.19]

Algorithm 8.3. *ACS-VEI algorithm for an iteration*



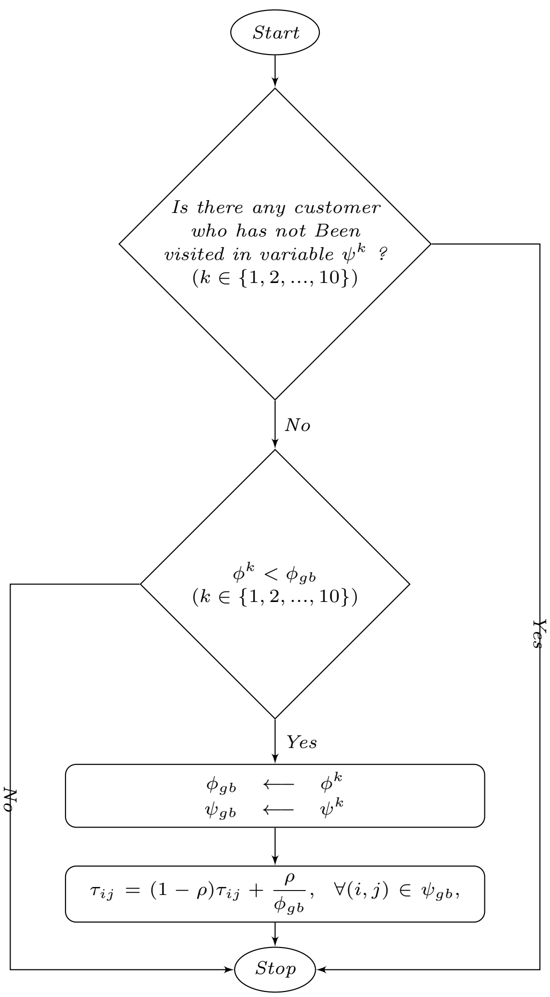
[DOI: 10.52547/ijmsi.17.2.19]

Algorithm 8.4. *ACS-TIME algorithm for one ant*



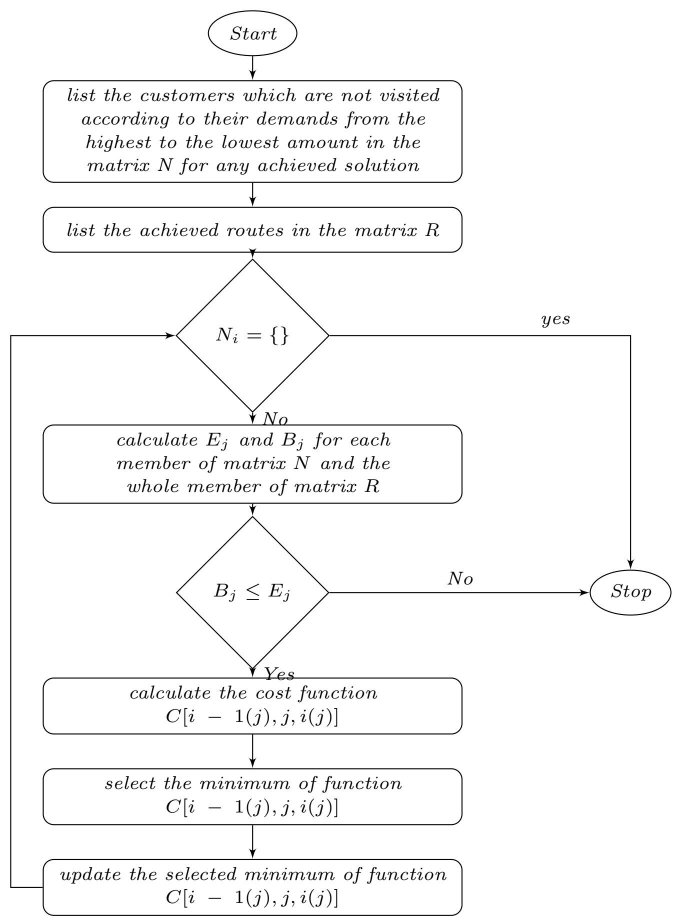
[DOI: 10.52547/ijmsi.17.2.19]

Algorithm 8.5. *ACS-TIME algorithm for an iteration*



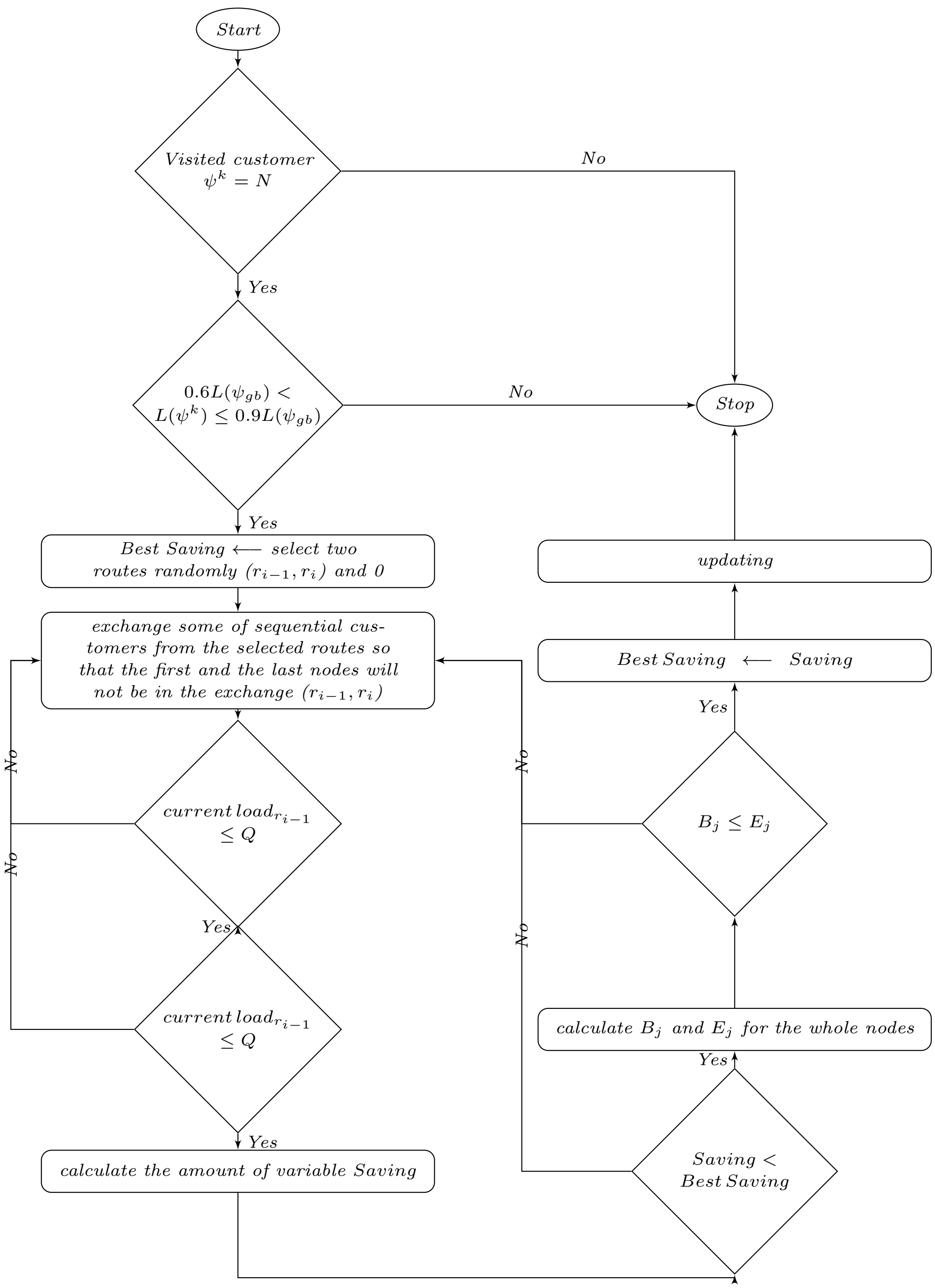
[DOI: 10.52547/ijmsi.17.2.19]

Algorithm 8.6. *Insertion Heuristic Algorithm*



[DOI: 10.52547/ijmsi.17.2.19]

Algorithm 8.7. *Cross-Exchange Algorithm*



[DOI: 10.52547/ijmsi.17.2.19]