Comparison of Simulated Annealing, Nearest Neighbour, and Tabu Search Methods to Solve Vehicle Routing Problems

Purnawan Adi Wicaksono, Diana Puspitasari, Sigit Ariyandanu, Rizka Hidayanti
Department of Industrial Engineering, Diponegoro University, Semarang, Indonesia

Email: purnawan@ft.undip.ac.id, sigitariyandanu@students.undip.ac.id

Abstract. The high cost of logistics is often caused by the determination of distribution routes, vehicle selection, and vehicle scheduling which is often referred to as Vehicle Routing Problem (VRP). VRP can be interpreted as determining the route with minimal costs to deliver goods from a depot to several different customers with different requests. PT Polar Ice Crystal Semarang is a company producing crystal ice that distributes crystal ice in the Semarang area. PT Polar Ice Crystal Semarang does not have a structured and systematic method in determining distribution routes so the company cannot calculate or know how effective the route travelled by the fleet. So far, the determination of distribution routes is left entirely to the driver of the fleet without any route instructions from the company. Therefore we need a method that can determine the distribution route so that the route passed can be effective in terms of cost and time of distribution. In this research, the determination of the optimal distribution route uses three different methods, namely the Simulated Annealing Algorithm, Tabu Search, and Nearest Neighbour. Then the best method is chosen that can produce the optimal route for the company. Based on the calculation results, it can be seen that the optimal route is obtained using the simulated annealing algorithm with estimated travel costs incurred in the amount of Rp. 293,000.17, with a distance of 88.66 km and a travel time of 9 hours 56 minutes using one large vehicle.

Keywords: vehicle routing problem; simulated annealing; nearest neighbour, tabu search

1. Introduction
The industry in Indonesia has recently experienced quite rapid development. This certainly has an impact on logistics activities that occur especially in terms of product distribution from producers to consumers which also increased. Logistics is a function that involves moving, managing the movement of goods, and storing material on its journey from the initial sender, through the supply chain and up to the end customer [1]. The logistics performance of a country can be measured using the Logistic Performance Index, which is an index that evaluates the logistics performance of 160 countries released by the World Bank with assessment components including customs, infrastructure, international shipments, logistics quality and competences, tracking and tracing, and timelines. Based on 2018 Logistics Performance Index data, Indonesia ranks 46th with a score of 3.15 [2]. Up from previous positions in the 2016 Logistics Performance Index ranked 63rd with a score of 2.98 [3]. This achievement is a significant achievement considering that there are still many obstacles faced by Indonesia. However, these positive achievements have not been offset by reduced logistics costs. Based on data from the Indonesian Logistics and Forwarders Association (ALFI), logistics costs in
Indonesia reached 25% of gross domestic product (GDP), higher than other countries in ASEAN, including Thailand (13.2%), Malaysia (13%), and Singapore (8.1%).

The high cost of logistics or distribution certainly has an impact on several things related to the product. If the cost of distribution is high, the cost of production for an item will be high and can certainly be detrimental to both the producers and consumers. In general, the logistics cost component can be grouped into three classifications, including transportation costs, storage costs, and administrative costs [4]. And more than 60% of logistics costs come from transportation costs [5]. Therefore, to minimize logistics costs, it can be done by minimizing transportation costs. Some of the main considerations in minimizing distribution costs include the selection of vehicle routes, vehicle fleets, and vehicle scheduling. These considerations are known as vehicle routing problems [6].

VRP was first studied by Dantzig and Ramser (1959) in the form of truck routing and scheduling, best known as The Truck Dispatching Problem [7]. Then Clarke and Wright (1964) continued the research by introducing the term depot and using the saving algorithm as a solution to the VRP problem [8]. VRP can be interpreted simply as determining the route with minimal costs to deliver goods from a depot to several different customers with different requests [9]. The main objective of VRP is to minimize distribution costs by minimizing vehicle mileage, vehicle travel time, or the number of vehicles used, while still meeting all existing restrictions. VRP problems are included in NP-hard problems (non-deterministic polynomial problems). A problem is said to be a non-deterministic polynomial problem if there is no definite algorithm in solving the problem, in other words, the algorithm for a solution can be modified to match the problem at hand [10]. VRP is often solved using a heuristic approach. A heuristic algorithm is a procedure that uses the structure of problems in a mathematical way to produce a feasible solution or a solution that is near-optimal [11]. But in VRP problems that are quite complex, metaheuristic methods are usually used. Metaheuristics is a more complicated repair procedure and can be seen as an improvement from classical heuristics [12].

In this research, the determination of the optimal distribution route uses three different methods, namely the Simulated Annealing Algorithm, Tabu Search, and Nearest Neighbour. Simulated annealing is taken from a process used in the metallurgical field, which is the gradual cooling of a metal material until it reaches its optimum crystal state. In the simulated annealing procedure, an artificial temperature is introduced as a stochastic source that shows the release of the solution from the local minimum trap [13]. The Tabu Search method was first introduced by Glover in 1990. Glover said that the Tabu Search procedure can be found in three main patterns, including the use of memory structures based on flexible attributes, the use of tabu restriction mechanisms, and involving memory structures with different terms different [14]. The nearest neighbour method builds a route solution by finding the closest points to the previous point, so in this case, it is very likely to occur local optima. The case discussed in this study is the VRP problem experienced by PT Polar Ice Crystal Semarang. The vehicle routing determination model developed in the vehicle routing problem (VRP) problem was made considering several constraints including the company having several types of vehicles (heterogeneous fleet), known transport capacity of each vehicle (fleet capacity), known operating time (time windows), and time service at each customer (service time).

2. Problem Description

The problem description contains an explanation of the company's condition as well as a description of the conceptual model so that it can be seen easily the flow and direction of the study.

2.1. PT Polar Ice Crystal Semarang

PT Polar Ice Crystal Semarang is a manufacturer of crystal ice and shaved ice, located in the city of Semarang. The company currently has 3 transport truck fleets consisting of 1 large truck fleet and 2 small truck fleets to distribute ice with different routes to Semarang and surrounding areas. Each fleet has a capacity of 2 tons (200 bags) for small trucks and 3.5 tons (350 bags) for large trucks. PT Polar Ice Crystal Semarang uses a direct selling system, meaning that the distribution and sale are carried
out by the same unit which is a fleet of transport trucks. In the process of determining the distribution route, PT Polar Ice Crystal Semarang does not yet have a structured and systematic method. The decision to take the route is entirely left to the driver who also acts as a salesperson. Determination of the route like this becomes a problem for the company because it cannot calculate or know how effective the route travelled by the fleet.

2.2. Conceptual Model
The conceptual model is a framework that provides a visual construction to help see the problem solving that will be carried out in this study.

![Conceptual Model Diagram]

**Figure 1. Conceptual Model**

3. Mathematical Model
The model is an imitation of a system that is arranged to resemble real conditions. For this reason, a model usually does not cover the whole situation but rather is adjusted to the research needs. Thus, in a mathematical model, there are several assumptions related to processes in the system.

3.1. VRP Variant
This study considers variants of Heterogeneous Fleet Vehicle Routing Problems with Time Windows (HFVRPTW):

- **VRP with Time Windows (VRPTW):**
  The formulation of vehicle routing problems with time windows (VRPTW) in general form with the objective function is to minimize the total cost. The model developed is still similar to the standard VRP model, the difference lies in the time window limitation [15]. The constraint used are capacity limits, time windows, each customer is visited once, and each route starts and ends at the depot. The VRPTW model forces the vehicle to arrive at the customer's location within a certain
time frame. Depots have an assumed identical time window called scheduling horizon and are represented by the notation \([a_0, b_0]\).

In the model created there are two decision variables namely \(x\) and \(s\). For each \((i, j)\), where \(i \neq j\), \(i \neq n + 1, j \neq 0\), and each vehicle \(k\), \(x_{ij}\) is defined as below:

\[
x_{ijk} = \begin{cases} 
0, & \text{if vehicle } k \text{ does not travel from point } i \text{ to point } j \\
1, & \text{if vehicle } k \text{ travels from point } i \text{ to point } j
\end{cases}
\]

The \(S_k\) decision variable shows the time the service was started to customer \(i\) by vehicle \(k\). If vehicle \(k\) does not serve customer \(i\), then \(S_k\) does not mean anything. Here is a mathematical model of the VRPTW problem:

- \(V\) = homogeneous fleet
- \(C\) = customers
- \(G\) = graph \(|C| + 2\) vertices
- \(N\) = node
- \(A\) = Arc
- 0 = depot as starting point
- \(n + 1\) = depot as ending point
- \(q\) = fleet capacity
- \(d_i\) = demand
- \(c_{ij}\) = cost
- \(t_{ij}\) = time elapsed
- \(a_i, b_i\) = time windows

\[
\begin{align*}
\text{Min} & \quad \sum_{k \in V} \sum_{i \in N} \sum_{j \in N} c_{ij} x_{ijk} \\
\text{Constraints:} & \\
\sum_{k \in V} \sum_{i \in N} x_{ijk} &= 1 \quad (2) \\
\sum_{i \in C} d_i \sum_{j \in N} x_{ijk} &\leq q \quad (3) \\
\sum_{j \in N} x_{0jk} &= 1 \quad (4) \\
\sum_{i \in N} x_{ihk} - \sum_{j \in N} x_{hjk} &= 0 \quad (5) \\
\sum_{i \in N} x_{i,n+1,k} &= 1 \quad (6) \\
s_{ik} + t_{ij} - K(1 - x_{ijk}) &\leq s_{jk} \quad (7) \\
a_i \leq s_{ik} \leq b_i \quad (8) \\
x_{ijk} &\in \{0,1\} \quad (9)
\end{align*}
\]

The objective function illustrated by equation (1) states that the purpose of this model is to minimize costs. The limiting function (2) states that each customer is visited exactly once. Limiting function (3) indicates a vehicle capacity limit. The limiting function (4) states that each vehicle departs from the depot. The limiting function (5) states that after visiting one customer the vehicle will move to the next customer. The limiting function (6) states that each vehicle will return and end at the depot. The limiting function (7) is used to state that vehicle \(k\) is not allowed to arrive at the customer location \(j\) before \(s_{ak} + t_{ij}\) or before the service start time and travel time from \(i\) to \(j\), where \(K\) is a real value of large value. Limiting function (8) is used to ensure that each customer's windows time constraints are met. The limiting function (9) states that the decision variable \(x_{ijk}\) is binary. Vehicles that are not used will have empty routes 0, \(n + 1\).

- **Heterogeneous Fleet VRP (HFVRP):**
  Gheysens, Golden, & Assad (1984) make formulations using binary variables with three indexes \(x_{ij}^{k}\) as a vehicle flow valued at 1 if a type \(k\) vehicle travels from customer \(i\) to customer \(j\), and 0 if it does not travel \([16]\). Besides that, there is another variable, namely \(y_{ij}\), which represents the amount
of goods carried when leaving customer i to customer j. The mathematical formulation of Heterogeneous Fleet VRP is as follows:

\[
\min \sum_{j \in V} F_k \sum_{i \in V} x_{ij}^k + \sum_{k \in M} \sum_{i,j \in V, i \neq j} c_{ij} x_{ij}^k 
\]

Constraints:
\[
\sum_{j \in V} x_{ij}^k \leq m_k 
\]
\[
\sum_{i \in V} y_{ij} - \sum_{i \in V} y_{ji} = q_j 
\]
\[
x_{ij}^k \leq y_{ij} \leq (Q_k - q_j) x_{ij}^k 
\]
\[
y_{ij} \geq \{0, 1\} 
\]

It can be seen in the formulation of the Heterogeneous Fleet VRP mathematical model above, that the objective function of the model is minimization (10). Limiting functions (11) limit the maximum number of vehicles available for each type of vehicle. The limiting function (12) requires that the difference in goods on a vehicle before and after visiting a customer be equal to the demand on that customer.

3.2. HFVRPTW Mathematical Model

The formulation of the model in this study was carried out by making a mathematical model. To know the behavior of the model simply and the interaction between variables and parameters in the model can be seen through mathematical model notation. The following is a mathematical model used in this study:

Notation:
\[
x_{ij}^k = \begin{cases} 
0, & \text{vehicle k doesn't travel from location i to location j} \\
1, & \text{vehicle k travel from location i to location j} 
\end{cases}
\]

\[
V_D = \text{Depot} \\
V_C = \text{Customers} \\
V = \text{Number of locations } (V_D \cup V_C) \\
q_i = \text{Demand location i} \\
s_i = \text{Service time location i} \\
[a_i, b_i] = \text{Time windows location i} \\
K = \text{Fleet type} \\
k = \text{Number of Fleet each Fleet type } (k \in K) \\
o_k = \text{Starting location vehicle k} \\
r_k = \text{Return locations vehicle k} \\
\tau_k = \text{Vehicle k starting time} \\
f_k = \text{Vehicle k fixed costs} \\
c_{ij}^k = \text{Vehicle k variable cost when travel from I to j} \\
Q_k = \text{Vehicle k capacity} \\
\bar{D}_k = \text{Vehicle k driving time limit} \\
W_k = \text{Vehicle k working time limit} \\
d_{ij} = \text{Distances between i to j} \\
\bar{d}_{ij} = \text{Durations between i to j} \\
z_{ij}^k = \text{Product shipped by vehicle k} \\
\tau_i^k = \text{Vehicle k arrival time} \\
\]

\[
\min \sum_{(i,j) \in A} \sum_{k \in K} c_{ij}^k x_{ij}^k + \sum_{j \in V} \sum_{k \in K} f_k x_{o_j}^k 
\]

Constraints:
\[
\sum_{j \in V} x_{o_j}^k \leq 1 
\]
\[
\sum_{i \in V} z_{ij}^k - \sum_{j \in V} z_{ij}^k = q_i \quad \text{(17)}
\]
\[
\sum_{i \in V} v_{ij}^k = \sum_{j \in V} v_{ij}^k \quad \text{(18)}
\]
\[
t^k_i + (d_{ij} + s_i)x_{ij}^k - W^k(1 - x_{ij}^k) \leq t^k_j \quad \text{(19)}
\]
\[
a_i \leq t^k_i \leq b_i - s_i \quad \text{(20)}
\]
\[
t^k_i = \tau^k \quad \text{(21)}
\]
\[
x_{ij}^k \leq Q^k \quad \text{(22)}
\]
\[
\sum_{(i,j) \in A} d_{ij} x_{ij}^k \leq D^k \quad \text{(23)}
\]
\[
\sum_{i \in V} s_i + \sum_{(i,j) \in A} d_{ij} x_{ij}^k \leq W^k \quad \text{(25)}
\]
\[
x_{ij}^k \in \{0, 1\} \quad \text{(26)}
\]
\[
z_{ij}^k \geq 0 \quad \text{(27)}
\]

The model created has an objective function to minimize costs associated with travel such as fixed costs and variable costs during the shipping or distribution process as can be seen in equation (15). The limiting function is explained by equation (16) to equation (27). Limiting function (16) is used to ensure that each customer can only be visited once by a certain vehicle. Limiting functions (17) and (18) are used to ensure the difference in goods on a vehicle before and after a tour. Function (19) is used to accommodate the time windows function for each customer. Limiting function (20) is a function used to define vehicle working time. Limiting function (21) is used to ensure the vehicle returns to the depot where the vehicle originated after a tour. Function (22) limits the vehicle's capacity to transport products. Limiting functions (24) and (25) limit the driving time and work time of the vehicle. Limiting functions (26) and (27) are non-negative constraints for the amount of goods.

4. Result

In this study, three methods were used to solve the VRP problem at PT Polar Ice Crystal Semarang including Nearest Neighbour, Tabu Search, and Simulated Annealing. The data used as a basis for calculation are customer location data (107 customers), customer demand data (Total 285 bags), and vehicle data owned (2 small vehicles and 1 large vehicle).

4.1. Nearest Neighbour

The first method used in this study is the Nearest Neighbour. The determination of the route is done by finding the closest customer to the location previously visited. The calculation is done using Microsoft Excel showed in Table 1.

| Table 1. Nearest Neighbour Results |
|-----------------------------------|
| **Parameter** | **Vehicle Used** | **2 Small** | **1 Large** | **1 Small 1 Large** |
| Total distances | 178.45 km | 150.16 km | 178.45 km |
| Total time | 6 hour 39 minute | 11 hour 26 minute | 6 hour 39 minute |
| Variable Cost | Rp. 131,249.98 | Rp. 154,664.80 | Rp. 168,967.84 |
| Fixed Cost | Rp. 395,799.10 | Rp. 201,680.37 | Rp. 399,579.92 |
| Total Cost | Rp. 526,959.85 | Rp. 356,345.17<sup>a</sup> | Rp. 568,547.757 |

*Best solution of Nearest Neighbour
4.2. **Tabu Search**

The second method used in this study is Tabu Search. The Tabu Search method is a metaheuristic method for solving combinatorial optimization problems. The combination is done to calculate how many exchanges must be done in each iteration [17]. The tabu search result is showed in table 2.

**Table 2. Tabu Search Results**

| Parameter     | Vehicle Used |          |          |
|---------------|--------------|----------|----------|
|               | 2 Small      | 1 Large  | 1 Small  |
| Total distances| 120.07 km    | 92.40    | 120.07 km|
| Total time    | 6 hour 31 minute | 9 hour 55 minute | 6 hour 31 minute |
| Variable Cost | Rp. 88,335.50 | Rp. 95,172.00 | Rp. 102,614.94 |
| Fixed Cost    | Rp. 395,799.10 | Rp. 201,680.37 | Rp. 399,579.92 |
| Total Cost    | Rp. 484,134.60 | Rp. 296,852.37 | Rp. 502,194.86 |

$^a$Best solution of Tabu Search

4.3. **Simulated Annealing**

The third method used in this study is the Simulated Annealing. The simulated annealing algorithm uses an analogy from the metallurgy field especially in the process of cooling iron. There are several parameters used to run this algorithm including initial temperature, final temperature, and cooling rate. The initial temperature used was 1000, the 1000 value for the initial temperature was chosen based on similar studies conducted previously by Supardi and Widiatomo (2002), Banchs (1997), and Hansmann and Okamoto (1994) who also used the value 1000 as the initial temperature. The final temperature in this study is 0.1, at this point iteration is expected to be enough to find the optimal solution but not too low so that the computation time is too long. The rate of temperature reduction used is $\alpha = 0.9$, referring to research conducted by Banchs (1997). The calculation is done using a Visual Basic for Application-based program. The result of simulated annealing is showed in table 3.

**Table 3. Simulated Annealing Results**

| Parameter     | Vehicle Used |          |          |
|---------------|--------------|----------|----------|
|               | 2 Small      | 1 Large  | 1 Small  |
| Total distances| 115.64 km    | 88.66 km | 114.25 km|
| Total time    | 5 hour 51 minute | 9 hour 56 minute | 6 hour 29 minute |
| Variable Cost | Rp. 85,076.35 | Rp. 91,319.80 | Rp. 94,365.99 |
| Fixed Cost    | Rp. 395,799.10 | Rp. 201,680.37 | Rp. 399,579.92 |
| Total Cost    | Rp. 480,875.45 | Rp. 293,000.17$^a$ | Rp. 493,945.92 |

$^a$Best solution of Simulated Annealing
4.4. Method Comparison
From the calculation results, it is known that the Nearest Neighbour method produces the best route using 1 large vehicle at a cost of Rp. 356,345.17, the total distance of the vehicle is 150.16 km with a travel time of 11 hours 26 minutes. The Tabu search method produces the best route using 1 large vehicle at a cost of Rp. 296,852.37, the total distance of the vehicle as far as 92.40 km with a travel time of 9 hours 55 minutes. The simulated annealing method produces the best route using 1 large vehicle at a cost of Rp. 293,000.17, the total distance of vehicles as far as 88.66 km with a travel time of 9 hours 56 minutes. Table 4 denotes a recapitulation calculation.

Table 4. Method Comparison

| Parameter          | Nearest Neighbour | Tabu Search    | Simulated Annealing |
|--------------------|-------------------|----------------|---------------------|
| No of Used Fleet   | 1 Unit            | 1 Unit         | 1 Unit              |
| Total Distances    | 150.16 km         | 92.40 km       | 88.66 km            |
| Total Time         | 11 hour 26 minutes| 9 hour 55 minutes| 9 hour 55 minutes |
| Total Cost         | Rp. 356,345.17    | Rp. 296,852.37 | Rp. 293,000.17*    |

*Best Solution

5. Conclusion
In this research, the delivery of ice cubes considers the type of vehicle used and the operating time of the company. Several methods are used to solve the distribution problem so that there are several possibilities to get the delivery route. The methods used include Nearest Neighbour, Tabu Search, and Simulated Annealing. Based on calculations made from these three methods produce several alternative routes using certain types of vehicles. This causes the costs to be incurred by the company to be varied. The variation in costs is due to the distance travelled in each method is different. The distance is directly proportional to the variable cost, the greater the distance travelled by the vehicle, the greater the cost of the company. Based on 3 alternative solutions obtained the lowest cost obtained using the Simulated Annealing method calculation of Rp. 293,000.17. Therefore, after calculating using three different methods, Simulated Annealing is more effective for use in distributing ice cubes. We hope that this research will provide insight into VRP issues. Also, it can conduct a deeper exploration of the algorithm used when considered from time efficiency.

References
[1] D. Waters, Logistics: an Introduction to Supply Chain Management, New York: Palgrave Macmillan, 2003.
[2] J.-F. Arvis, L. Ojala, C. Wiederer, B. Shepherd, A. Raj, K. Dairabayeva and T. Kiiski, "Connecting to Compete 2018 Trade Logistics in the Global Economy," The World Bank, Washington, 2018.
[3] J.-F. Arvis, D. Saslavsky, L. Ojala, B. Shepherd, C. Busch, A. Raj and T. Naula, "Connecting to Compete 2016 Trade Logistics in the Global Economy," The World Bank, Washington, 2016.
[4] Zaroni, "Biaya Logistik Agregat," 15 April 2017. [Online]. Available: http://supplychainindonesia.com/new/biaya-logistik-agregat/.
[5] Zaroni, "Transportasi dalam Rantai Pasok dan Logistik," 18 Agustus 2015. [Online]. Available: http://supplychainindonesia.com/new/transportasi-dalam-rantai-pasok-dan-logistik/.
[6] S. Raff, "Routing and scheduling of vehicles and crews: The state of the art," Computers & Operations Research, vol. 10, no. 2, pp. 63-211, 1983.
[7] G. B. Dantzig and J. H. Ramser, "The Truck Dispatching Problem," Management Science, vol. 6, pp. 80-91, 1959.
[8] G. Clarke and J. W. Wright, "Scheduling of Vehicles from a Central Depot to a Number of Delivery Points," *Operations Research*, vol. 12, no. 4, pp. 568-581, 1964.

[9] O. Bräysy and M. Gendreau, "Genetic Algorithms for The Vehicle Routing Problem With Time Windows," *Arpakannus*, vol. 1, pp. 33-38, 2001.

[10] S. Cook, "The Importance of the P versus NP Question," *Journal of The ACM*, vol. 50, no. 1, pp. 27-29, 2003.

[11] M. Ball, L. Bodin and R. Dial, "A Matching Based Heuristic for Scheduling Mass Transit Crews and Vehicles," *Transportation Science*, vol. 17, no. 1, pp. 4-31, 1983.

[12] P. Toth and D. Vigo, *The Vehicle Routing Problem*, Philadelphia: Society for Industrial and Applied Mathematics, 2002.

[13] C. Tsallis and D. A. Stariolo, "Generalized simulated annealing," *Physica A: Statistical Mechanics and its Applications*, pp. 395-406, 1996.

[14] Glover, "Tabu Search : part II ORSA," *Journal on Computing 1*, 2, pp. 4-32, 1990.

[15] B. Kallehauge, J. Larsen and O. B. Madsen, "Lagrangean Duality applied on vehicle routing with time windows - Experimental results," Technical University of Denmark, Lyngby, 2001.

[16] F. G. Gheysens, B. Golden and A. Assad, "A comparison of techniques for solving the fleet size and mix vehicle routing problem," *Operations Research-Spektrum*, vol. 6, pp. 207-216, 1984.

[17] C. Herawati, H. Adianto and F. H. Mustofa, "Usulan Rute Distribusi Tabung Gas 12 Kg Menggunakan Algoritma Nearest Neighbour dan Algoritma Tabu Search," *Reka Integra*, vol. Vol.03, pp. 209-220, 2015.

[18] Supardi and R. Widiatmono, "Penyelesaian Fungsi Non-Konveks Menggunakan Teknik Optimasi Berbasis Annealing," Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Negeri Yogyakarta, Yogyakarta, 2002.

[19] R. E. Banchs, "Simulated Annealing," *Research Progress Report*, 1997.

[20] U. H. Hansmann and Y. Okamoto, "Comparative Study of Multicanonical and Simulated Annealing Algorithms in The Protein Folding Problem," *Physica A: Statistical Mechanics and its Applications*, pp. 415-437, 1994.