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Travelling Salesman Problem to solve KFC Chicken delivery by Using Simulated Annealing Method and Greedy Method

Foo Sin Yew[1], Wan Rohaizad Wan Ibrahim[2*]
Department of Mathematical Sciences, Faculty of Science, UTM, Skudai, Johor Bahru, Malaysia
*Corresponding author: wrohaizad@utm.my

Abstract
The problem of this study, which is classified as the Travelling Salesman Problem (TSP), is to obtain the optimum route and cost when delivering the KFC chicken from QSR Manufacturing Sdn. Bhd. to 29 KFC branches at Shah Alam and returning to the QSR company by using Simulated Annealing (SA) and the Greedy Method. C++ software is used to solve the problem. The Greedy Method is a heuristic algorithm that makes the locally optimal choice at each stage. SA is a random local search technique based on the principle's physics. The approach draws inspiration from the analogy of the cooling and annealing processes observed in metals. The result of SA is compared with the Greedy Method. Based on the result obtained, the Greedy Method selects the most suitable choice based on the current situation, which may not lead to the overall optimum result. It is always trapped at the local optimum. In contrast, SA is a continuous search technique designed to avoid becoming ensnared in local maxima. The results indicate that the SA approach outperforms the Greedy Method, consistently achieving the optimal cost more frequently.
Keywords Travelling Salesman Problem; Simulated Annealing; Greedy Method

Introduction

QSR Brands (M) Holdings Bhd (QSR Brand) stands as Malaysia's esteemed and exclusive vertically integrated culinary enterprise, distinguished by its commitment to delivering farm-to-fork excellence in both products and services. The first KFC restaurant in Malaysia was in 1973, and QSR Brands is the only company granted the right by Yum! QSR Brands operates with more than 850 KFC restaurants across Malaysia, Singapore, Brunei, and Cambodia, complemented by a presence of over 480 Pizza Hut establishments in Malaysia and Singapore.

Other than restaurant operations, they are also involved in various facets of the food chain, especially chicken, such as breeding, contract farming, meat production, processing, hatcheries, and so on. It also includes other ancillary businesses such as confectioneries, bread processing, and sauce manufacturing. QSR Manufacturing Sdn. Bhd. is a company located in Glenmarie, Shah Alam, that produces and supplies bakery and commissary products such as pizza dough, sanitized vegetables, daily products to all KFC and Pizza Hut restaurants, and so on.

In this research, it will focus on the delivery of the chickens from QSR Manufacturing Sdn. Bhd. to all the KFC branches at Shah Alam and back to the starting point, which is QSR Company. The Simulated Annealing (SA) and Greedy Method will be used to solve this problem. The objective of this research is to find the optimal route and cost to travel from QSR Manufacturing Sdn. Bhd. to all the KFC branches at Shah Alam and minimize the distances. Other than that, to compare the results in solving Travelling Salesman Problem (TSP) obtained between the Greedy Method and SA. There are 29 KFC branches in Shah Alam. Delivery of KFC material is part of their job scope. This challenge falls under the purview of the TSP, a quintessential optimization conundrum.

Literature Review

For the literature review, a succinct overview and comprehensive understanding of previous research conducted by researchers regarding the Travelling Salesman Problem (TSP) are provided. The Simulated Annealing (SA) and Greedy Method that were used to solve TSP are reviewed.

Travelling Salesman Problem (TSP)

The Travelling Salesman Problem (TSP) is a routing problem to find the shortest way to visit all the cities and return to the starting point. This problem was formulated in 1930 by William Rowan Hamilton and Thomas Kirkman, who are mathematicians. For example, it can be used when a salesman wants to travel around the cities with the shortest distance, which can reduce the cost and return to the beginning. It is a classical combinatorial optimization problem and NP-hard problem that is difficult to solve. In the field of Operational Research (OR), many heuristic algorithms have been developed to solve problems, such as the Greedy Method, Ant Colony Optimization (ACO) algorithms, Simulated Annealing (SA), Tabu Search (TS), Genetic algorithms (GA), and so on. The applications of the TSP are vehicle routing, manufacturing of microchips, drilling in printed circuit boards, packet routing in GSM, computer wiring, mission planning problems, and so on [1]. It can be represented as an undirected weighted graph with cities acting as its vertices, paths acting as its edges, and the length of an edge representing a path's distance, as shown as below Figure 1, which is the overview of TSP.

Figure 1 Overview of Travelling Salesman Problem (TSP) [2]

Greedy Method

The origins of the Greedy algorithm can be traced back to the early work of Edsger W. Dijkstra. In 1959, a Dutch computer scientist proposed the Greedy algorithm to solve the unit shortest path problem. The advantages of this method are its simplicity, efficiency, and ease of implementation. The Greedy algorithms have many applications in scheduling problems and travelling salesman problems. In scheduling problems, the application for the Greedy algorithm is skip idle time, shortest job priority, earliest deadline first, and least time-consuming priority. The Greedy algorithm uses 2 strategies in TSP which is nearest neighbor strategy and the minimum spanning tree strategy. The nearest neighbor strategy begins at a starting city and repeatedly selects the closest, least-visited city as the next destination until all cities have been visited. This method is simple and fast, but it does not guarantee an optimal solution. The minimum spanning tree strategy involves constructing a minimum spanning tree and then traversing its nodes using depth-first search (DFS) to generate a path. While this approach also does not guarantee an optimal solution, it generally produces better results than the nearest neighbor strategy [3].

The Greedy Method is a heuristic algorithm that makes the locally optimal choice at each stage. Although this method does not produce the optimal solution for many problems, it can produce locally optimal solutions that approximate a globally optimal solution. This method will be the best choice at that moment, without regard to future consequences. It never rescinds its choices or decisions made earlier. If an objective function is assumed to need to be maximized or minimized at a specific point in time, a Greedy Method makes decisions at each step to guarantee that the objective function is optimized at that point without considering the impact on future decisions and does not reverse the decision later [4].

2-Optimization (2-opt)

2-opt is namely as two optimization algorithm that was introduced by Croes in 1985 year. This method is a simple local search algorithm. To reduce the overall length of the route, an edge swap is performed in the tour [5]. The 2-Opt algorithms, branches of local search algorithms, are commonly employed by the theoretical computer science community to solve the TSP. The 2-Opt algorithm works by removing two edges from the graph and then reconstructing it to complete the cycle. There is only one possible way to add two unique edges to the graph to complete the cycle. If the new tour length is shorter than the previous one, the new configuration is accepted; otherwise, it is rejected [6]. In the Figure 2, there is a route that passes through cities A, B, C and D. The left figure has two paths that intersect with each other, which are lines AD and CB. To minimize the distance, a new path will be formed which is the AD and CB paths will be replaced with the AB and CD paths, which will decrease the overall route distance.

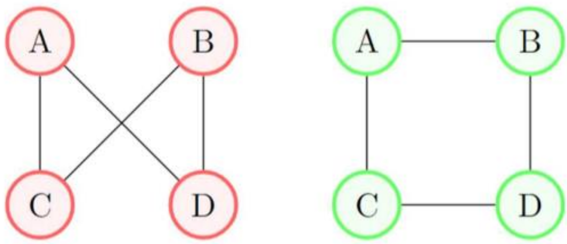

Figure 2 Example of swapping two random paths [5]

Simulated Annealing (SA)

This method was introduced by Kirkpatrick et al. in 1983 and Cerny in 1985. Simulated Annealing (SA) is a random local search technique based on the principle's physics. The approach draws inspiration from the analogy of the cooling and annealing processes observed in metals. When a liquid metal undergoes gradual cooling, its atoms will form a crystal structure corresponding to the metal's state of minimum energy. Conversely, rapid cooling leads the metal to adopt a higher energy state, resulting in an imperfect crystal formation. Kirkpatrick et al. and Cerny demonstrated the applicability of a model proposed by Metropolis et al. for simulating the annealing process in solid. This can be used for optimization where the objective function will be minimized to correspond to the energy states of the material. In the late 1980s, SA garnered significant interest to finding the solution to the optimization problem and emerged as one of several heuristics' methods. This method can be used to solve combinatorial optimization problems. These problems are classified as NP-hard problems. TSP belongs to this NP-hard problem where the salesman visits numerous cities only once and returns to the starting point to make sure the route is as short as possible [1].

SA stands as a stochastic optimization algorithm, drawing inspiration from the annealing process in metallurgy. This method begins with randomly generating an initial solution, followed by a gradual reduction in the system's temperature. As the temperature decreases, the method will more easily accept worse solutions to escape local optima [7]. This method has become popular over the past two decades due to its straightforward implementation, favourable convergence properties, and ability to escape local optima by using hill-climbing moves. SA establishes a link between thermodynamic principles and the search for global minima in discrete optimization problems. At each iteration of the SA method, two solutions which is the current solution and the new solution that was generated from the objective function will be compared. The improving solutions will be accepted, while the probability of accepting non-improving (inferior) solutions depends on the temperature parameter [8].

This method allows non-improving moves by computing the acceptance probability to determine whether the non-improving solution can be acceptable or not. The formula for acceptance probability is shown below.

$$p(\delta) = e^{-\frac{\delta}{T_k}} \tag{1}$$

A random number, *r*, is generated to compare with the acceptance probability. The non-improving move is accepted if the random number is smaller and equal to the acceptance probability; otherwise, the solution is rejected.

Table 1: The parameters for Simulated Annealing

Parameters	Description
Initial Temperature, T_0	The initial temperature should be sufficiently high to ensure that any newly generated solution in a state transition is accepted with a probability close to 1.
Temperature decreases function	The formula, $T_k = \alpha T_{k-1}$ is used which is geometric cooling scheme where, T_k is current temperature and T_{k-1} is the previous temperature. The α is a parameter called the cooling ratio which is between 0 to 1. Commonly, the α suitable value is fluctuating between 0.8 and 0.99. The rate at which the temperature decreases is crucial for the performance of the simulated annealing algorithm. If the temperature decreases too quickly, the algorithm may get stuck in local minima. Conversely, if it decreases too slowly, the algorithm may take too long to converge to a good solution.
Final Temperature	It is customary to gradually decrease the final temperature until it approaches zero. As the temperature converges towards zero, the probability of acceptance also will approach zero. This will cause the non-improving move will not to be accepted.
Number of state transitions, *L*	The number of state transitions at each temperature should be sufficiently high to ensure that no solution changes will be accepted.

Methodology

Formulation for Travelling Salesman Problem (TSP)

Let $d_{ij} = \text{Distance from city } i \text{ to city } j$, where $i, j = 1, \ldots\ldots, n$

$$c_{ij} = \begin{cases} 1, \ if\ the\ city\ i\ reached\ to\ city\ j \\ 0, \ otherwise \end{cases}$$

Min

$$\sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij}\, c_{ij}$$

Subject to

$$\sum_{i=1, i\neq j}^{n} c_{ij} = 1 \qquad (2)$$

$$\sum_{j=1, j\neq i}^{n} c_{ij} = 1 \qquad (3)$$

$$\sum_{i} \sum_{j} c_{ij} \leq S - 1, \forall S \subset v, 2 \leq |S| \leq n - 2 \qquad (4)$$

Data Collection

Figure 3 shows 29 KFC locations in Shah Alam on a Google Map screenshot. This grid is drawn using an online ArtTutor, and the coordinates are set to 100 by 100. This figure is used to find the coordinates of the KFC locations.

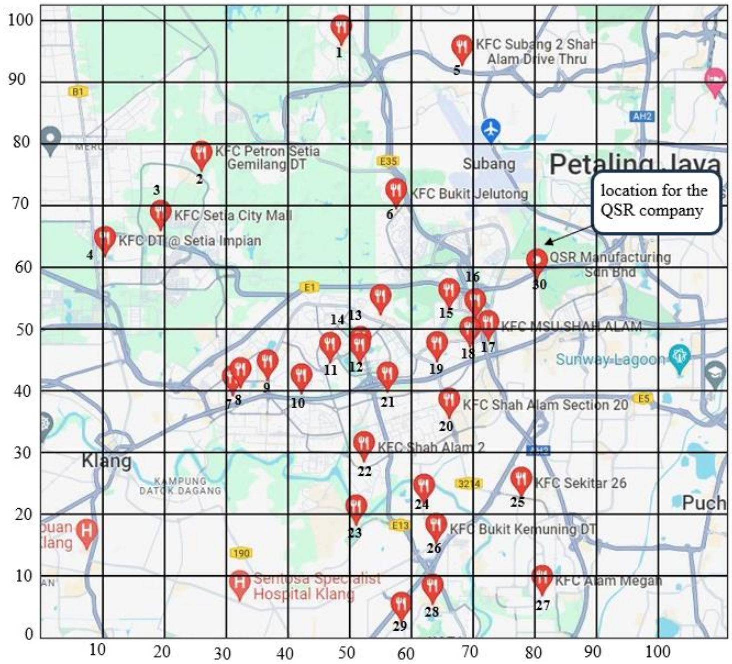

Figure 3 Location of the QSR Manufacturing Sdn. Bhd. and 29 KFC branches in Shah Alam

The data is taken the locations from all KFC branches at Shah Alam and the QSR Manufacturing Sdn. Bhd. company. There are 29 KFC branches in Shah Alam. The coordinates represent the location of each KFC branch and QSR company. The coordinate for the QSR company is location 30, while the other coordinates represent the locations of the 29 KFC branches in Shah Alam as shown in Table 2.

Table 2: Coordinates for the KFC branches at Shah Alam and QSR Manufacturing Sdn. Bhd.

Location	Coordinate (x, y)	Location	Coordinate (x, y)
1	(48,96)	16	(70,52)
2	(26,75)	17	(72,49)
3	(19,66)	18	(70,47)
4	(10,62)	19	(63,45)
5	(68,92)	20	(66,35)
6	(58,70)	21	(56,40)
7	(31,39)	22	(52,28)
8	(32,40)	23	(51,18)
9	(36,42)	24	(62,21)
10	(42,39)	25	(78,22)
11	(46,45)	26	(64,15)
12	(52,45)	27	(81,7)
13	(52,47)	28	(63,5)
14	(55,52)	29	(58,2)
15	(65,53)	30	(80,58)

Flow Chart for Greedy Method

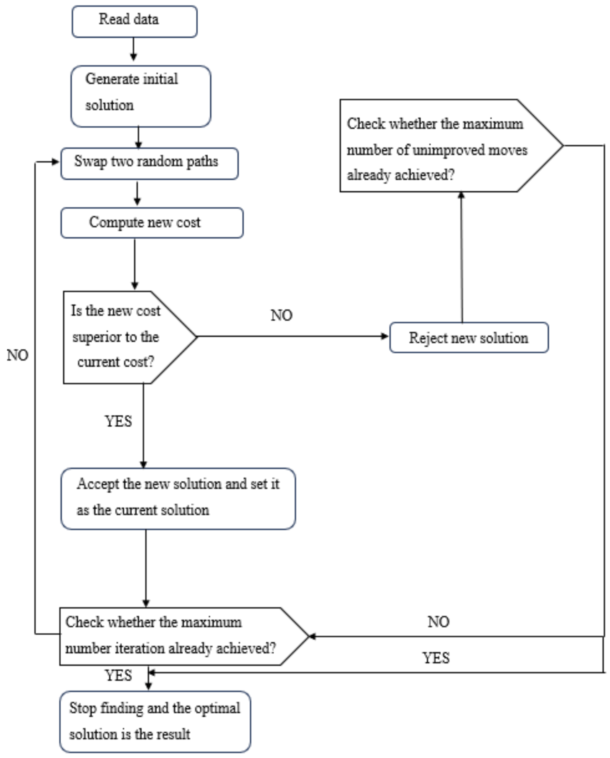

Figure 4 Flow Chart for Greedy Method

Flow Chart for Simulated Annealing

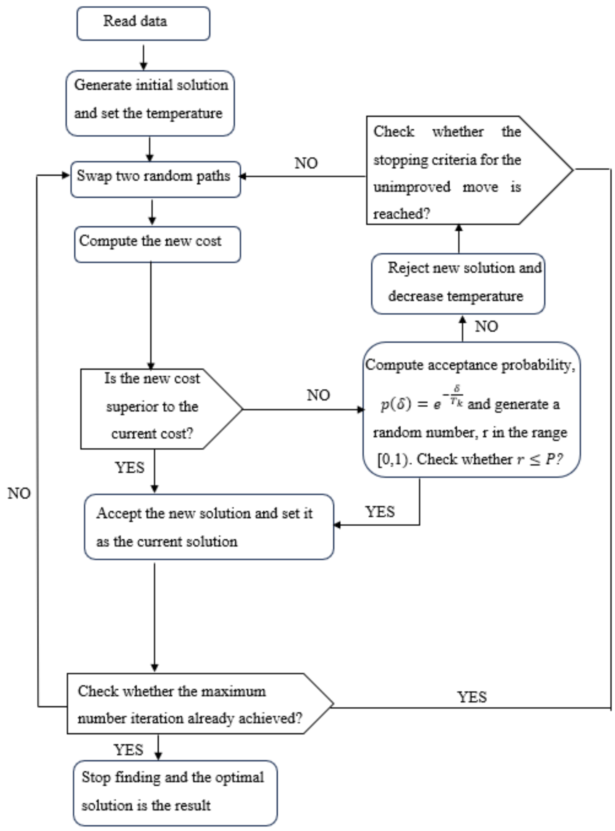

Figure 5 Flow Chart for Simulated Annealing

Problem-solving technique

Initial solution for Simulated Annealing and Greedy Method

To fulfill the criteria of the Travelling Salesman Problem, the vehicle embarks on its journey from the depot, which is QSR company, and proceeds to the subsequent KFC branches. Upon visiting all KFC branches, the vehicle is required to return to the depot. To tackle the TSP, the initial solution is obtained by choosing the nearest KFC branches. So, the vehicle will travel to each of the nearest KFC branches exactly once before returning to the depot. The complete initial solution for the vehicle to travel to all KFC branches exactly once and return to QSR Company is shown below.

DEPOT → 16 → 17 → 18 → 19 → 15 → 14 → 13 → 12 → 11 → 10 → 9 → 8 → 7 → 22 → 23 → 24 → 26 → 28 → 29 → 27 → 25 → 20 → 21 → 6 →5 → 1 → 2 →3 → 4 → DEPOT
Initial cost: 408.786 per unit distance

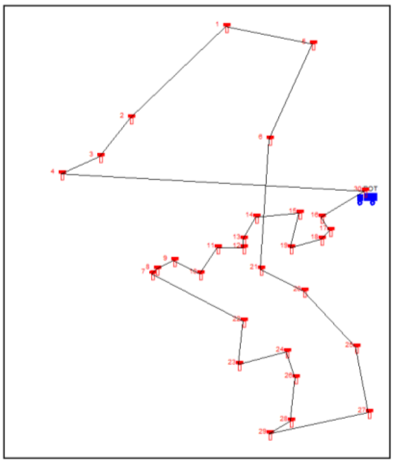

Figure 6 The complete initial solution for Greedy Method and Simulated Annealing

Swap two random paths

The moves involve randomly selecting two paths and swapping them. After swapping the two paths, the route will be altered. So, the cost needs to be calculated again. After swapping two random paths, the new solution will be accepted if the new cost is better than the current cost. The SA has a chance to accept the non-improving moves by computing the probability of acceptance, while the Greedy Method will reject the worst solution.

Greedy Method

In this research, the Greedy 2-opt algorithm is used to solve the TSP, which is a simple local search algorithm. The search will stop once one of the stopping criteria is met, whichever comes first. When the search stops, the current solution will be set as the final solution or result.

The stopping criteria for the Greedy Method is the number of maximum unimproved moves achieved and the number of maximum iterations achieved. In this research, the maximum number of iterations to be used is 1000 times the number of locations. The chickens are being delivered to 29 branches of KFC at Shah Alam. So, the maximum number of iterations in this case is 29000. The maximum number of consecutive non-improving moves with the limit set at 50 times the number of locations. Consequently, in this case, the search terminates following 1450 consecutive non-improving moves.

Simulated Annealing (SA)

Simulated Annealing (SA) is an effective and widely used method of optimization especially in finding the global optimal when there are large numbers of local optima. This method usually starts with the initial solution. There are 4 parameters that need to be set in the reheat SA which is initial temperature, cooling schedule, maximum number of non-improving solutions, and maximum number of iterations.

To set the initial temperature, the formula $T_1 = 0.2C_1$ is used. $C_1$is the cost of the initial solutions which is 408.786 per unit distance. After substituting the value of C_1, the initial temperature is 81.7572. The formula for the temperature iteration is $T_k = 0.925T_{k-1}$. The value of the cooling rate, α to be chosen is 0.925 which is between 0 to 1. The stopping criteria for Simulated Annealing is the maximum number of iterations to be used is 1000 times the number of locations which is 29000. After that, the system was reheated 10 times and 3 times of reheating did not yield a better solution.

Reheat

In Simulated Annealing (SA), the reheating process is applied when the total number of rejected moves reaches a certain value. The reheat process enables the method to continue the exploration if there is no improvement in the solution after a certain number of iterations where the temperature will be reset. The temperature reset formula is $T_k = 0.3C_0$ where the C_0 is current optimal cost. When the temperature is exceedingly high, the SA process will become a random search due to the elevated likelihood of accepting all moves. Conversely, as the temperature approaches zero, the process will become the Greedy Method because the probability of acceptance is near zero. The reheating process will be introduced to ensure a continued search for a better solution when the temperature approaches zero. This strategy aims to allow the algorithm to better explore the search by giving a higher probability in accepting a worst candidate solution.

Results and discussion

The C++ programming computer software to be used to solve the Travelling Salesman Problem (TSP). To find the optimal cost, 12 runs have been done in C++, as shown in Table 3. The search methods to be used are Simulated Annealing (SA) and the Greedy Method.

Table 3: The optimal cost using the Simulated Annealing and Greedy Method through 12 runs

Run	Simulated Annealing		Greedy Method	
	Number of iteration	Optimal cost (per unit distance)	Number of iteration	Optimal cost (per unit distance)
Initial		408.786		408.786
1^{st}	27549	354.579	3953	357.522
2^{nd}	27514	**351.228**	2897	366.292
3^{rd}	24503	**351.288**	2357	358.328
4^{th}	12281	352.223	2897	**351.228**
5^{th}	18364	354.579	1646	372.722
6^{th}	15295	**351.228**	2673	358.328
7^{th}	12289	**351.228**	2532	357.840
8^{th}	21436	354.139	3548	352.223
9^{th}	15341	357.522	2341	355.385
10^{th}	21393	**351.228**	2108	355.385
11^{th}	24474	**351.228**	2373	358.518
12^{th}	15330	**351.228**	3058	361.854

Based on Table 3, the SA and Greedy Method manage to find the optimal cost, which is 351.228 per unit distance. After 12 runs in C++, the SA method manages to find the optimal cost in 7 runs out of 12 runs, but the Greedy Method only has 1 run to find the optimal cost. So, the Greedy Method selects the most suitable choice based on the current situation and ignores the current best result, which may not lead to the overall optimum result. It is always trapped at the local optimum. SA is a continuous search technique that avoids becoming ensnared in local maxima. From the result, it can be observed that the SA approach is better than the Greedy Method which can obtain the optimal cost on a more frequent basis.

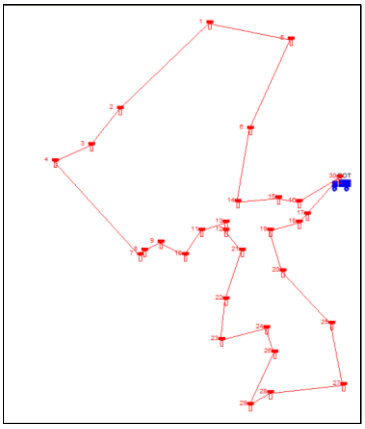

Figure 7 The final optimal route obtained using Greedy and Simulated Annealing method

The figure above shows the final route, and it is the best route to deliver the chicken from QSR company to the 29 branches KFC at Shah Alam. This route can save both cost and time for the QSR company. The figure below shows the complete optimal route for how the transport begins the tour and returns to the QSR company.

DEPOT → 17 → 18 → 19 → 20 → 25 → 27 → 28 → 29 → 26 → 24 → 23 → 22 → 21 → 12 → 13 → 11 → 10 → 9 → 8 → 7 → 4 → 3 → 2 → 1 → 5 → 6 → 14 → 15 → 16 → DEPOT

Optimal cost = 351.228 per unit distance

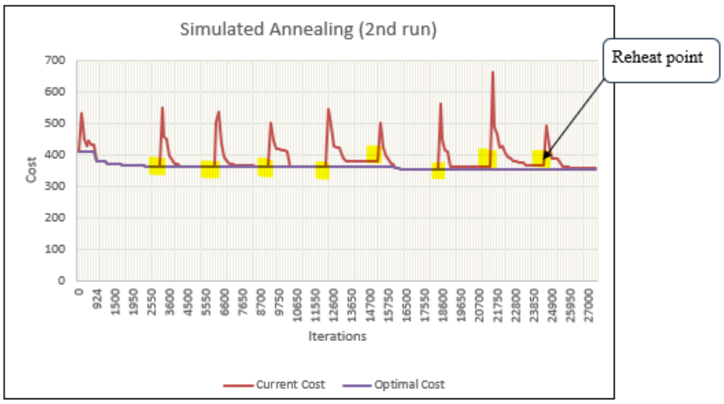

Figure 8 The graph of optimal cost and current cost versus iterations for Simulated Annealing in 2nd run

In SA, if the current solution is better than the new solution, there is a chance to accept the new solution by computing the probability of acceptance. The temperature is the control parameter in SA. The probability progressively decreases as the temperature is reduced. The method used to achieve this temperature reduction is commonly referred to as a cooling schedule. The gradual reduction in temperature yields the best solution. It has been observed that after an extended period of temperature reduction, the method eventually reaches the same point as the Greedy Method, where no further improvements can be made upon reaching a local optimum. To address this, reheat technique is used, and the temperature is increased after a certain number of iterations. After reheating, the temperature increases, which increases the probability of accepting the worst solution. It can escape from the local optima and explore the search space to find a better solution. Reheat SA allows the algorithm to do the exploration when there is no improvement in the current solutions after a certain number of iterations. As shown in Figure 8, the results indicate better convergence to the solution following this reheating process. After reheating, the cost will increase due to accepting the worst solution, but it will slowly decrease and converge to the optimal cost.

Conclusion

In this research, a transport is used to deliver the chicken from QSR company to 29 branches of KFC at Shah Alam. All the locations are visited exactly once and returned to the QSR company. The aim of this research is to find the optimal route and cost to improve the delivery KFC chicken route efficiency for the QSR company. Other than that, minimize the travelling distance from QSR Manufacturing Sdn. Bhd. to all KFC branches at Shah Alam. The objective of the research has already been achieved. The methods that are used to solve delivery chicken problem in this research are SA and the Greedy Method. The result of the Greedy Method is compared with the SA method. Two of these methods were able to find an efficient route and an optimal solution.

Acknowledgement

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References

[1] C. Dahiya and S. Sangwan. (2018). Literature review on travelling salesman problem. International Journal of Research, vol. 5, no. 16, pp. 1152-1155.

[2] S. Thukral and C. Diwaker.(2017). Travelling Salesman Problem Using Various Optimization Techniques.

[3] Y. Wang.(2023). Review on greedy algorithm. Theoretical and Natural Science, vol. 14, pp. 233-239.

[4] M. H. Rashid and M. A. Mosteiro.(2017). A greedy-genetic local-search heuristic for the traveling salesman problem. IEEE International Symposium on Parallel and Distributed Processing with Applications and IEEE International Conference on Ubiquitous Computing and Communications (ISPA/IUCC), pp. 868-872.

[5] P. Gunawan and I. Iryanto.(2023). Simulated Annealing – 2 Opt Algorithm for Solving Traveling Salesman Problem. International Journal of Computing, vol. 22, no. 1, pp. 43-50.

[6] F. Uddin, N. Riaz, A. Manan, I. Mahmood, O. Y. Song, A. J. Malik and A. A. Abbasi.(2023). An improvement to the 2-opt heuristic algorithm for approximation of optimal TSP tour. Applied Sciences, vol. 13, no. 12, p. 7339.

[7] S. M. Almufti, A. A. Shaban, Z. A. Ali, R. I. Ali and J. A. D. Fuente.(2023). Overview of metaheuristic algorithms. Polaris Global Journal of Scholarly Research and Trends, vol. 2, no. 2, pp. 10-32.

[8] D. Henderson, S. H. Jacobson and A. W. Johnson, “The theory and practice of simulated annealing,” Handbook of metaheuristics, pp. 287-319, 2003.