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Solving Route Planning in Harvest Operation of Corn Based on Travelling Salesman Problem Using Simulated Annealing

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Abstract
The Traveling Salesman Problem (TSP) is a well-known combinatorial optimization problem that has been widely studied in various fields. In the context of agricultural operations management, this thesis focuses on applying the TSP to solve the route planning problem in the harvest operation of corn. The TSP aims to find the most optimal route that visits each field only once and then returns to the starting point, while minimizing the total travel distance and time. In this study, the Simulated Annealing (SA) algorithm is employed to solve the TSP. SA is a metaheuristic optimization technique that iteratively search and refines potential solutions, to avoid being trapped at the local optimum with a probability. The SA algorithm is implemented using Microsoft Visual Studio C++, enabling efficient and scalable computation to tackle the extremely time-consuming process involving large amounts of data. The findings of this research contribute to the field of agricultural operations management by providing practical solutions for optimizing route planning in corn harvest operations.

Keywords: Travelling Salesman Problem (TSP); Simulated Annealing (SA); Optimization.

1. Introduction

The agricultural sector faces an increasing number of logistical issues, making it crucial to optimize resource use and the amount of time needed to manage and conduct field operations on expanding fields [21]. Moreover, scattered farm fields cause workers to take plenty of time to travel among them and hence involve routing for efficient work. Yet, workers who lack expertise find it challenging to operate farm machinery, or plan routes [15]. Therefore, the Traveling Salesman Problem (TSP) can be used to determine the shortest route through all the farmland from the machinery depot to the place where the corn needs to be harvested.

The TSP, also known as the Traveling Salesman Problem, is a prevalent issue in many business organizations that simulates salespeople moving between cities. It involves scheduling and combinatorial optimization and can be described as a salesman traveling cyclically to n cities (or nodes).

The solution to any TSP would be the shortest route or distance for the harvesting process by the machinery, which would involve travelling only once across each cornfield before returning to the depot. This study aims to plan the shortest distance of the harvest operation and to minimize the time taken of harvest operation. With that, the harvest yield can distribute faster.

This study is done by considering that farm machinery is used as the main operational tool and the loading capacity of the machinery is enough to travel once, for the whole corn field. In this study, a

TSP modelling using Simulated Annealing algorithm is implemented using Microsoft Visual C++ software to approach the best route of corn harvesting.

2. Travelling Salesman Problem

The Traveling Salesman Problem is an optimization problem that has numerous applications, including machine sequencing, computer wiring, combinatorial data analysis, scheduling, planning, and logistics for moving vehicles. In his paper, Liao [11] has designed new algorithm of TSP based on the agriculture machinery problem operation path optimization and concluded that the heuristic method has reference relevance in solving actual large-scale TSP that can effectively improve the operation efficiency.

A salesman visits each of the given number of cities or towns in such a way that each city is visited once, the total distance travelled is minimal and must return to the first node or original node.

TSP can be modelled as stated below:

Min

$$C = \sum_{i=0}^{n} \sum_{j=0}^{j=i} x_{ij} d_{ij}$$

$$0 \leq x_{ij} \leq 1, \qquad i, j = 0, \ldots n$$

Subject to

$$\sum_{i}^{n} x_{ij} = 1;\ \forall i \neq j$$

$$\sum_{j}^{n} \mathrm{x_{ij}} = 1;\ \forall i \neq j$$

$$x_{ij} = \begin{cases} 1, & the\ path\ goes\ from\ farm\ i\ to\ farm\ j \\ 0, & otherwise \end{cases}$$

Where C is the time taken, and d_{ij} is the distance between the field that need to be minimize during the harvest process. The x_{ij} is in order to prevent the farmer from returning to one of the fields that he has already been to before he has finish visited all the farms.

The time taken for this problem or for Euclidean Traveling Salesman Problem is the sum of total distance travelled. The distance between two farm fields can be calculated by the formula:

$$d_{ij} = \sqrt{(x_i - x_j) + (y_i - y_j)}, \qquad ij = 0,1,2,3, \ldots, n$$

3. Simulated Annealing

Simulated Annealing is a method that provides for the occasional uphill move in an effort to prevent becoming stuck in poor local optima. This is carried out while being influenced by a temperature control parameter and a random number generator.

The basic steps of Simulated Annealing (SA) applied to the TSP are described below.

1. Neighbourhood: At each step, a neighbourhood solution is selected by an exchange of a randomly selected pair of nodes. The randomly generated neighbour solution is selected if it improves the

solution else it is selected with a probability that depends on the extent to which it deteriorates from the current solution. Probability of acceptance is a probability to accept non-improving move.

$$P(\delta) = e^{-\left(\frac{\delta}{T_k}\right)}$$

Where T_k is the current temperature and δ is the change of time taken.

2. Termination criteria: The algorithm terminates if it meets any one of the following criteria:
   a. It reaches a pre-specified number of iterations.
   b. There is no improvement in the solution for last pre-specified number of iterations.
   c. Fraction of neighbour solutions tried that is accepted at any temperature reaches a pre-specified minimum.

In this study, the maximum number of iterations is set to 1,000 times the number of fields, resulting in a total of 20,000 iterations for this TSP problem. Additionally, another stopping criterion for the SA process is when the system has been reheated ten times.

Simulated Annealing in TSP

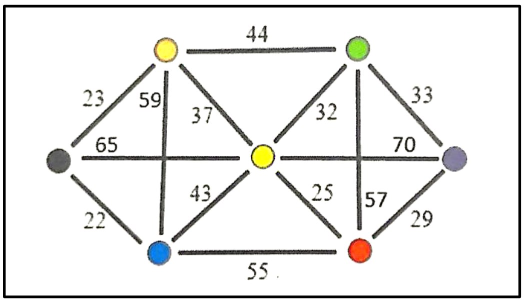

Figure 1 Distance between two points

In Figure 1, it shows the distance between the points. Let the black point be the starting point. Each point can only pass once and finishing the track at the point of origin. which is the black point.

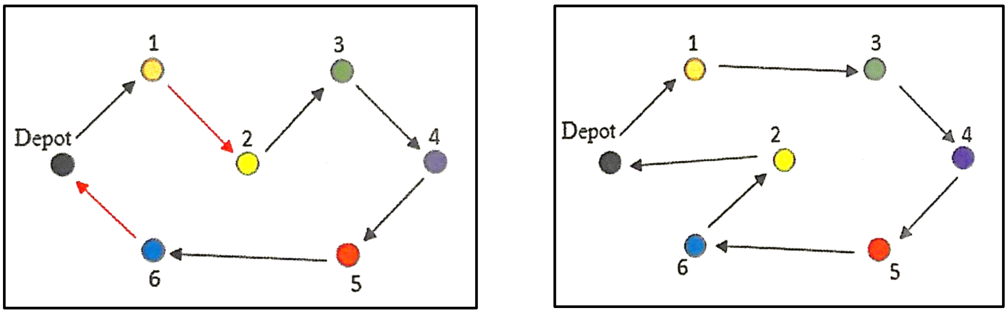

Figure 2 Moves in TSP

Current solution: D-1-2-3-4-5-6-D
Total time taken=231m, Optimal=231m

New solution: D-1-3-4-5-6-2-D
Total time taken=292m, Optimal=231m

Figure 2 illustrates one of the solutions of the optimization problems, TSP. Note that path 1-2 and 6-D has been changed to the new path 1-3 and 6-2. Current cost is 231 and the new time taken after swapping two path is 292 minutes. In the TSP, the objective is to minimize the time taken. So, in this case the time taken has been increased and the move is non-improving moved. So, we must calculate the probability of acceptance. Let the current temperature, T is 80 and the random number generated is 0.4433.

$$P(\delta) = e^{-\left(\frac{292-231}{80}\right)} = 0.4665$$

Since the random number generated is less than the probability calculated, we accept the new move, and the next move should begin from the new solution. If the other solution gives us the better time taken, the other solution will be accepted.

4. Results and discussion

The data utilized in this project consists of simulated data, which is subject to modification depending on the specific problem being investigated. The dataset was limited to 20 fields for this demonstration. Each field is represented by X and Y coordinates, within the range of 0 to 100 for both axes.

In satisfying the definition of TSP, the transportation process initiates from the depot and proceeds to the next corn field. To solve the TSP, an initial solution is generated by selecting the closest field. Starting from the initial move, the machinery then progresses to the subsequent nearest fields using the same approach, ensuring it does not revisit any previously visited fields. Once all the fields have been visited, the machinery is required to return to the depot.

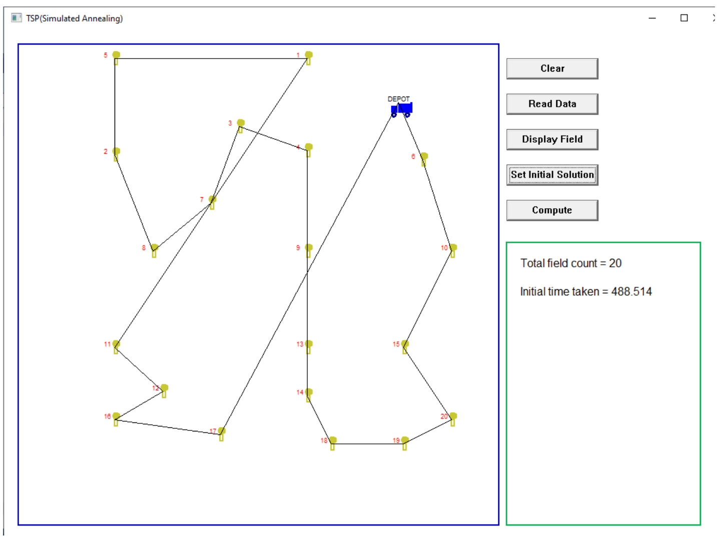

Figure 3 Initial route

The complete tour for initial solution is given as follows.

DEPOT - 6 - 10 - 15 - 20 - 19 - 18 - 14 - 13 - 9 - 4 - 3 - 7 - 8 - 2 - 5 - 1 - 11 - 12 - 16 - 17 – DEPOT
Initial time taken = 488.514

By using Microsoft Visual C++, further runs have been repeated ten times using the same initial solution and the result has been recorded as shown in Table 1 below.

Table 1: The result of different runs for Simulated Annealing

Run	Number of iterations	Optimal time taken
Initial		488.514
1st Run	10200	390.788

2nd Run	8135	383.614
3rd Run	8141	383.614
4th Run	12238	380.875
5th Run	8170	380.875
6th Run	8112	380.875
7th Run	8110	380.875
8th Run	8114	380.875
9th Run	8180	380.875
10th Run	8145	380.875

From the table above, the best value obtained is at 8110 iterations. After a few runs, the SA method manages to reach the global optimum. The figure in green shows the minimum time taken of 380.875.

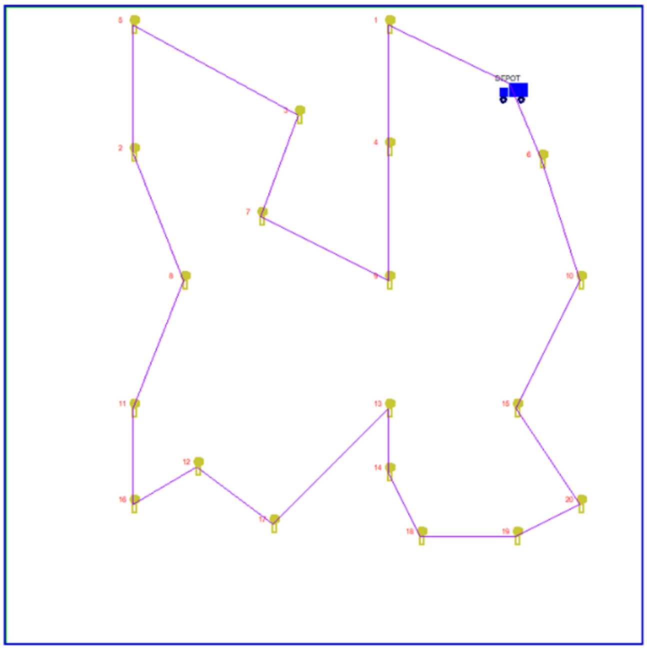

Figure 4 Final solution

Route:

DEPOT - 1 - 4 - 9 - 7 - 3 - 5 - 2 - 8 - 11 - 16 - 12 - 17 - 13 - 14 - 18 - 19 - 20 - 15 - 10 - 6 – DEPOT, Time taken = 380.875

Figure 4 shows the final route computed using the SA method. This solution is generated within less than a second.

Conclusion

This research focuses on utilizing the Simulated Annealing heuristic method to tackle the corn harvest problem among scattered farm fields in agricultural corporation, which can be formulated as a variant of the traveling salesman problem. From the SA method computed, the optimal route took 380.875 minutes for the machinery to travel from the depot to visit all the corn fields once before returning back to the depot. Therefore, the SA method has demonstrated its ability to generate high-quality solutions within a reasonable computational time, without exhaustively exploring every single possible solution. In the context of the corn yield harvest problem, SA shows promise in providing efficient solutions that optimize the time required for machinery-based harvesting operations. However, it is only limited to no constraints in this study. Hence, introducing a river constraint to the problem can introduce a higher level of complexity and realism. This could be achieved by incorporating a cost or penalty associated with crossing the river during the corn harvest operation.

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