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A Food Transportation Model for Optimizing Driver Allocation and Minimizing Total Distance in the Chicken Farm Business Network:
(A Case Study of Nakhon Ratchasima Province, Thailand)

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Abstract

The chicken farm operations in Nakhon Ratchasima Province, Thailand, prioritize stringent hygiene standards across production, transportation, and employee protocols. One critical regulation prohibits employees from bringing or consuming external food within farm premises to prevent contamination risks. Consequently, centralized meal preparation with strict cleanliness control is mandated, and meals are delivered to various farm units within the supply chain. Daily food transportation involves delivering three meals to 12 farms, necessitating 36 trips per day. Drivers work 8 hours daily, with a 1-hour break and a 1-hour vehicle maintenance post-delivery, and they are legally entitled to one day off per week. This results in driver shortages and the absence of decision-support tools for optimal route planning, leading to delivery delays and overtime work. This study aims to develop a mathematical model to optimize driver allocation and route planning, ensuring minimal total travel distance using principles from the Traveling Salesman Problem (TSP). The results demonstrate a reduction in each driver's trips from 4 to 3 per day, achieving the minimum total travel distance. Additionally, the model successfully allocates the daily workforce to 3 drivers and facilitates weekly rest day scheduling. This approach significantly enhances operational efficiency and adherence to hygiene protocols in the chicken farming industry.

Keywords
Route Optimization, Traveling Salesman Problem (TSP), Chicken Farm Logistics, Hygiene Protocols, Driver Allocation

1. Introduction
The operation of poultry farms within the network of poultry companies in Nakhon Ratchasima and Buriram provinces is crucial in maintaining biological, hygienic, and health safety standards for the chickens. Biosecurity is essential for preventing disease outbreaks and maintaining the health of the chickens on the farms. To prevent the spread of pathogens, strict regulations have been established, including prohibiting employees from bringing outside food into

the farms. Food preparation from a central kitchen and daily transportation to various farms is a process that requires meticulous planning and management.

In the network area of Nakhon Ratchasima and Buriram, covering a total of 8 districts, the transportation of food to the network farms necessitates efficient route planning. Since food must be delivered to all farms, careful planning is needed. With 4 drivers alternating their days off and 4 delivery routes, additional planning is required to ensure food delivery on the days when a driver is off. Efficient route planning can reduce both the distance and time needed for transportation, and can also decrease the overtime burden on drivers. One popular method for managing delivery routes is the Traveling Salesman Problem (TSP) theory, which aids in finding the optimal delivery path. Applying TSP theory to food transportation within the poultry farm network can significantly reduce both the distance and time required for food delivery. Developing effective driver allocation and leave planning can minimize overtime work and enhance food transportation efficiency.

Evaluating food transportation efficiency using indicators and tools such as Google Maps and tracking software helps to visualize and improve overall transportation efficiency. Improving the food transportation system by applying TSP theory demonstrates the benefits of reducing the number of delivery rounds per day and the total distance covered. Efficient driver management and leave planning ensure continuous food delivery operations. Implementing TSP theory in managing food delivery routes in the poultry farm network in Nakhon Ratchasima and Buriram is key to enhancing food transportation efficiency and maintaining consistent hygiene standards.

1.1 Objectives

- To study, analyze, and optimize food transportation routes to achieve the minimum total distance by using the Traveling Salesman Problem (TSP) theory.
- To develop an effective driver allocation model and leave planning to reduce overtime work and enhance food transportation efficiency.

2. Literature Review

Development of Maritime Logistic Network Model of Indonesia, (Adi D. E., and Ishak D.2021) Coking Coal Industry This study proposes a cross-docking model as a solution to the logistical challenges faced by the coking coal industry in Indonesia. A case study at PT. XYZ validates the model's effectiveness in reducing costs. Optimization of Vehicle Routes, Location of Transfer Stations and Landfills Based on Geographic Information Systems in Depok City, (Aghimien, D. and Aigbavboa, Tb.2021) This study demonstrates the effectiveness of using GIS to optimize waste management systems. By strategically locating transfer stations and landfills, Depok City can improve waste collection efficiency, reduce transportation costs, and minimize environmental impact.

Examining the spatiotemporal changing pattern of freight maritime transport networks in Indonesia during COVID-19 outbreaks, (Destyanto, A. R., Huang, Y., & Verbraeck, A. 2021) COVID-19 disrupted Indonesia's maritime freight network, shifting it from a centralized to a multi-hub structure. This led to new regional hubs and reduced long-haul capacity, potentially increasing costs. The study recommends a resilient network and policy support for eastern regions. An Empirical Investigation of Factors Affecting Humanitarian Logistics Operations: The Case of Palestine. (Kittaneh, R. M., and Jaaron, A. A. M. 2023). While the study provides valuable contributions, it is essential to acknowledge its limitations. The focus on Palestine restricts the generalizability of the findings to other contexts. Future research could explore the applicability of these results to different humanitarian settings. Additionally, qualitative research methods could be incorporated to provide deeper insights into the challenges and opportunities faced by HL practitioners. Solving an Interscholastic Bus Routing Problem, (Rosas, A. M., García-Colis, B., Valencia-Torres, P. S., and Díaz-Ramírez J. 2023). The interscholastic transportation solution improves resource utilization and demand coverage compared to traditional methods, satisfying 31.25% more students while using half the number of buses. This validates the model's potential for enhancing transportation efficiency between universities in the Monterrey metropolitan area.

3. Methods

The primary objectives of this research are to study, analyze, and optimize food transportation routes to achieve the minimum total distance using the Traveling Salesman Problem (TSP) theory and to develop an effective driver allocation model and leave planning to reduce overtime work and enhance food transportation efficiency. The scope of this research does not cover external factors that might affect transportation, such as weather conditions, traffic, or uncontrollable emergencies, nor does it include other management aspects beyond food transportation. Data Collection; The research begins with the collection of data needed for the study. This includes current food transportation route data, such as distance, travel time, and encountered issues. Additionally, data on farm locations and the number of farms requiring food delivery each day, driver information including the number of drivers, work schedules, leave schedules, and daily food delivery requirements are also collected.

Performance Indicators; The defined performance indicators include the total transportation distance and the number of daily delivery rounds. The Traveling Salesman Problem (TSP) theory is chosen as the evaluation tool to find the optimal route for minimizing total travel distance. Furthermore, data analysis software is employed to analyze route data and driver work patterns. Prototype Development; A prototype for evaluating system efficiency is developed, starting with the collection of route and work data, including driver work schedules and other relevant information. Subsequently, the food transportation routes are analyzed and optimized by applying the TSP theory, and driver leave management is analyzed to determine effective management strategies.

Evaluation and Continuous Improvement; The results are evaluated using performance indicators such as the reduction in total distance and the number of delivery rounds. Continuous improvement uses evaluation results to refine routes and driver leave management to enhance operational efficiency. Finally, the improvement results are assessed and documented. The optimized routes are evaluated to observe the reduction in total distance and the number of delivery rounds post-optimization. Driver leave management results are evaluated to ensure that drivers have weekly rest days without affecting their colleagues. The research findings are summarized and proposed for continuous improvement to enhance operational efficiency.

4. Data Collection

Currently, food transportation to farms within the network is managed using a total of four pickup trucks, each assigned to a dedicated driver. These trucks are responsible for delivering food three times a day to various farms located in two provinces: Nakhon Ratchasima (covering Wang Nam Khiao, Chok Chai, Pak Thong Chai, Chakkarat, and Nong Bunnak districts) and Buriram (covering Prakhon Chai, Nang Rong, and Non-Suwan districts). The transportation routes are divided into four main routes.

Figure 1. The current routes for transporting food to the farm consist of 4 routes

Detailed data on the current food transportation routes has been collected, including distances, travel times, and encountered issues. Additionally, information about farm locations and the number of farms requiring food delivery each day has been gathered. Data on drivers, such as the number of drivers, work schedules, and days off, has also been recorded. Daily food quantities to be transported have been collected to facilitate accurate planning and scheduling.

Table 1. Current Food Transportation Routes

Distance (Km.)								
Route 1	Depot	BD12	P6	P9	P8	BD7	Depot	Total Km.
	0	33	43	3	7	33	36	155
Route 2	Depot	P7	BD10	BD9	BD8	Depot	Total Km.	
	0	27	44	2	17	40	130	
Route 3	Depot	BD6	BD5	Depot	Total Km.			
	0	36	41	73	150			
Route 4	Depot	BD11	Depot	Total Km.				
	0	77	77	154				
Route 2+4	Depot	P7	BD10	BD9	BD8	BD11	Depot	Total Km.
	0	27	44	2	17	51	77	218

Summary of Total Distances for Transportation Routes
The total distances for the transportation routes can be summarized as follows:

- Monday, Tuesday, and Wednesday: Routes 1,2,3 and 4 have a combined total distance of 589 kilometers per round. With 3 rounds per day, the total distance is 1,767Km./day.
- Thursday, Friday, Saturday, and Sunday: Routes 1,3and 2+4 have a combined total distance of 506 kilometers per round. With 3 rounds per day, the total distance is 1,518Km./day.

Table 2. Driver Work Schedule and Holiday Plan

Schedule plan & Holiday							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Driver 1	Route 1	Route 1	Route 1	Holiday	Route 3	Route 3	Route 1+2
Driver 2	Route 2	Route 2	Route 2	Route 1+2	Holiday	Route 4	Route 4
Driver 3	Route 3	Route 3	Route 3	Route 3	Route 1+2	Holiday	Route 3
Driver 4	Route 4	Route 4	Route 4	Route 4	Route 4	Route 1+2	Holiday

The work schedule and leave plan for the drivers are as follows

- Driver 1: Drives Route 1 from Monday to Thursday, Saturday, and Sunday. Has a day off on Friday.
- Driver 2: Drives Route 2 from Monday to Wednesday, Route 2 on Friday, and Route 3 on Saturday and Sunday. Has a day off on Thursday.
- Driver 3: Drives Route 3 from Monday to Thursday and Sunday. Has a day off on Saturday.
- Driver 4: Drives Route 4 from Monday to Wednesday, and Route 4+2 from Thursday to Saturday. Has a day off on Sunday.

Performance Metrics and Evaluation

The performance metrics defined include the total transportation distance and the number of delivery rounds per day. Under normal route conditions, each driver works 8 hours a day, covering an average distance of 147 kilometers per round. However, Route 2+4, with a distance of 218 kilometers, requires an additional 30 minutes per round, resulting in 1.5 hours of overtime work per day for 4 days a week.

Optimization using TSP

To evaluate the current system's performance, the Traveling Salesman Problem (TSP) theory was applied to find the optimal route to minimize the total distance. Data analysis software was used to evaluate the route information and the drivers' work schedules to improve route planning and staff management. This data collection and analysis help enhance the efficiency and productivity of the transportation system.

Performance Metrics

The performance metrics defined include the total transportation distance and the number of delivery rounds per day under normal route conditions. To improve transportation efficiency and reduce the total distance, the application of the Traveling Salesman Problem (TSP) theory was used to redesign the food transportation routes from four routes to three routes. This approach ensures that the shortest routes are selected and that drivers have regular weekly days off. Data analysis software was employed to analyze route information and driver schedules to identify more efficient routes and manage driver work effectively.

Route Analysis and Improvement

The analysis and improvement of food transportation routes were conducted by applying the TSP theory to reduce the total distance and the number of delivery rounds. The analysis of driver leave management was also conducted to find effective management methods. The results were evaluated using performance metrics such as the reduction in total distance and the number of delivery rounds. Continuous improvement utilized the evaluation results to continuously refine the routes and driver leave management.

Finally, the improved routes were evaluated to observe the reduction in total distance and the number of delivery rounds after the improvements. The results of the driver leave management were evaluated to ensure that drivers have regular weekly days off without affecting their colleagues. The research findings were summarized and proposed as continuous improvement guidelines to enhance operational efficiency.

Selection of Evaluation Tools. Traveling Salesman Problem (TSP) with Current Operational System

The Traveling Salesman Problem (TSP) is a mathematical and computer science problem that seeks the shortest possible route that visits each city (or point) exactly once and returns to the starting city. By using TSP to address the food transportation route management issue, more efficient routes and staff management can be achieved. Applying the TSP theory to plan food transportation routes in the current operational system of the chicken farm network aims to enhance transportation efficiency and shorten the total distance by finding the best routes (Optimal Routes) for the TSP problem. Several computational techniques can be used to solve the TSP, such as heuristic algorithms and metaheuristic algorithms, which can help find the routes with the minimum total distance.

5. Results and Discussion

The expected research outcomes from applying the Traveling Salesman Problem (TSP) theory to food transportation in a farm network can be summarized as follows. Using TSP will significantly reduce the total daily transportation distance from the current total distance by optimizing the routes. This reduction in transportation time will decrease drivers' over time, allowing them more rest and reducing fatigue, which positively impacts their health and work efficiency.Applying TSP will also facilitate the optimal allocation of drivers to transportation routes, ensuring smooth operations without disruptions due to employee absences. Work schedules and leave management for drivers will become more efficient. Reducing the total transportation distance will lead to lower fuel consumption, which in turn will help reduce operational costs for the farm network. Lower fuel usage will save expenses and lessen environmental impact.

The computational techniques that can be utilized include the Nearest Neighbor Heuristic (NNH), which starts from one point and selects the shortest route to the next point until all points are covered; the Genetic Algorithm (GA), which employs principles of natural evolution by generating multiple solution sets, selecting, crossing over, and improving them to find the optimal route; and Simulated Annealing (SA), which uses the principle of slow cooling in physical processes, improving solutions by accepting slightly worse changes to avoid local optima. This research expects that the results from applying these techniques will enhance the efficiency of food transportation, reduce energy consumption and costs, and improve driver management effectively.

5.1 Numerical Results

Finding the Optimal Routes. To identify the three optimal routes, we begin with the Nearest Neighbor Heuristic (NNH) to determine the initial routes. Subsequently, the Genetic Algorithm (GA) or Simulated Annealing (SA) is applied to improve the results.

Table 3. Distance matrix in the context of the Traveling Salesman Problem (TSP).

Distance (Km.)													
From / To	Depot	P6	P7	P8	P9	BD5	BD6	BD7	BD8	BD9	BD10	BD11	BD12
Depot	0	17	10	13	17	73	36	36	40	44	46	77	33
P6	17	0	13	4	3	76	42	41	50	54	56	87	43
P7	10	13	0	20	14	79	43	47	38	42	44	78	27
P8	13	4	20	0	7	72	38	37	50	54	56	90	39
P9	17	3	14	7	0	76	44	48	54	41	43	88	40
BD5	73	76	79	72	76	0	41	51	110	115	116	157	99
BD6	36	42	43	38	44	41	0	15	73	77	79	98	63
BD7	36	41	47	37	48	51	15	0	70	73	75	91	59
BD8	40	50	38	50	54	110	73	70	0	17	19	51	51
BD9	44	54	42	54	41	115	77	73	17	0	2	60	54
BD10	46	56	44	56	43	116	79	75	19	2	0	61	56
BD11	77	87	78	90	88	157	98	91	51	60	61	0	88
BD12	33	43	27	39	40	99	63	59	51	54	56	88	0

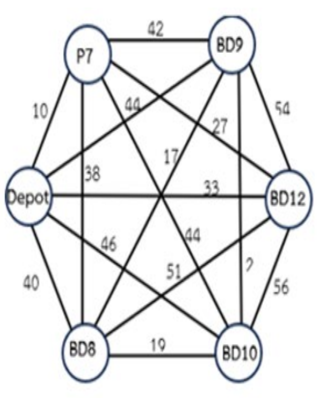
Calculation Steps

The data is divided into 3 groups, and the optimal route for each group is calculated using the Traveling Salesman Problem (TSP). We utilize both a heuristic approach, the Nearest Neighbor Heuristic (NNH), and a metaheuristic approach, Simulated Annealing (SA). To ensure balance, points are allocated to each group such that each has a similar number of points to visit.

The groups are organized based on main road routes that are either the same or in close proximity, as follows.

- Group 1: Main Road Route 24 (Southbound). Depot, P7, BD8, BD9, BD10, BD12.

Table 4. Distance matrix in the context of the Traveling Salesman Problem (TSP) Group 1.



Distsnce (Km.)						
From \ To	Depot	P7	BD8	BD9	BD10	DB12
Depot	0	10	40	44	46	33
P7	10	0	38	42	44	27
BD8	40	38	0	17	19	51
BD9	44	42	17	0	2	54
BD10	46	44	19	2	0	56
DB12	33	27	51	54	56	0

Table 5. Distance Matrix Calculate" in the context of the Traveling Salesman Problem (TSP) Group 1.

No.	Point Start and End	Distance	Km.
1	Depot -> P7 -> BD8 -> BD9 -> BD10 -> DB12 -> Depot	10 + 38 + 17 + 2 + 56 + 33	156 Km.
2	Depot -> P7 -> BD8 -> BD9 -> DB12 -> BD10 -> Depot	10 + 38 + 17 + 54 + 56 + 46	221 Km.
3	Depot -> P7 -> BD8 -> BD10 -> BD9 -> DB12 -> Depot	10 + 38 + 19 + 2 + 54 + 33	156 Km.
4	Depot -> P7 -> BD8 -> BD10 -> DB12 -> BD9 -> Depot	10 + 38 + 19 + 56 + 2 + 44	169 Km.
5	Depot -> P7 -> DB12 -> BD10 -> BD9 -> BD8 -> Depot	10 + 27 + 56 + 2 + 17 + 40	**152 Km.**
6	Depot -> BD8 -> BD9 -> BD10 -> DB12 -> P7 -> Depot	40 + 17 + 2 + 56 + 27 + 10	**152 Km.**
7	Depot -> BD8 -> BD10 -> BD9 -> DB12 -> P7 -> Depot	40 + 19 + 2 + 54 + 27 + 10	**152 Km.**
115	Depot -> DB12 -> BD10 -> P7 -> BD8 -> BD9 -> Depot	33 + 56 + 27 + 38 + 17 + 2	173 Km.
116	Depot -> DB12 -> BD10 -> P7 -> BD9 -> BD8 -> Depot	33 + 56 + 27 + 42 + 17 + 40	215 Km.
117	Depot -> DB12 -> BD10 -> BD8 -> P7 -> BD9 -> Depot	33 + 56 + 51 + 38 + 42 + 2	222 Km.
118	Depot -> DB12 -> BD10 -> BD8 -> BD9 -> P7 -> Depot	33 + 56 + 51 + 17 + 42 + 10	209 Km.
119	Depot -> DB12 -> BD10 -> BD9 -> P7 -> BD8 -> Depot	33 + 56 + 54 + 27 + 38 + 40	248 Km.
120	Depot -> DB12 -> BD10 -> BD9 -> BD8 -> P7 -> Depot	33 + 56 + 54 + 51 + 38 + 10	242 Km.

(a)

```
import numpy as np
import random

distance_matrix = np.array([
    [0, 10, 40, 44, 46, 33],
    [10, 0, 38, 42, 44, 27],
    [40, 38, 0, 17, 19, 51],
    [44, 42, 17, 0, 2, 54],
    [46, 44, 19, 2, 0, 56],
    [33, 27, 51, 54, 56, 0]
])

def calculate_total_distance(route, distance_matrix):
    total_distance = 0
    for i in range(len(route) - 1):
        total_distance += distance_matrix[route[i], route[i + 1]]
    return total_distance

      Nearest Neighbor Heuristic (NNH)
def nearest_neighbor(route, distance_matrix):
    unvisited = set(route)
    current = route[0]
    new_route = [current]
    unvisited.remove(current)
    while unvisited:
        next_city = min(unvisited, key=lambda city: distance_matrix[current, city])
        new_route.append(next_city)
        unvisited.remove(next_city)
        current = next_city
    new_route.append(route[0])
    return new_route
```

(b)

```
      Simulated Annealing (SA)
def simulated_annealing(route, distance_matrix, initial_temp, cooling_rate, max_iterations
    def swap_two_cities(route):
        new_route = route[:]
        i, j = random.sample(range(1, len(route) - 1), 2)
        new_route[i], new_route[j] = new_route[j], new_route[i]
        return new_route

    current_route = route
    current_distance = calculate_total_distance(current_route, distance_matrix)
    best_route = current_route
    best_distance = current_distance
    temp = initial_temp

    for _ in range(max_iterations):
        new_route = swap_two_cities(current_route)
        new_distance = calculate_total_distance(new_route, distance_matrix)
        if new_distance < current_distance or random.random() < np.exp((current_distance -
            current_route = new_route
            current_distance = new_distance
            if current_distance < best_distance:
                best_route = current_route
                best_distance = current_distance
        temp *= cooling_rate

    return best_route, best_distance
initial_route = [0, 1, 2, 3, 4, 5, 0]

nnh_route = nearest_neighbor(initial_route, distance_matrix)
best_route, best_distance = simulated_annealing(nnh_route, distance_matrix, initial_temp=

print( best_route)
print(best_distance)
```

Figure 2. (a) Demonstration of Using Function Nearest Neighbor Heuristic (NNH). (b) Function Simulated Annealing (SA) Group 1.

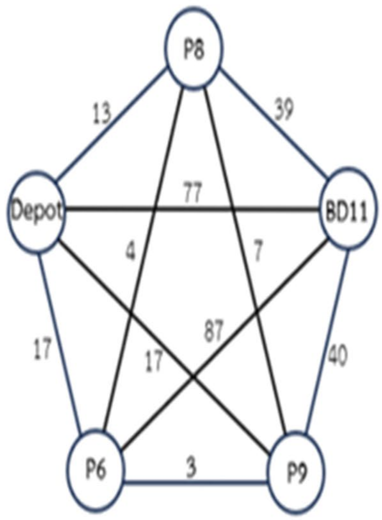
Based on the calculation of all 120 routes & calculate by python, the best route for Group 1 = 152 km

Detail of the best route

- Depot -> P7 -> DB12 -> BD10 -> BD9 -> BD8 -> Depot = 152 km
- Depot -> BD8 -> BD9 -> BD10 -> DB12 -> P7 -> Depot = 152 km
- Depot -> BD8 -> BD10 -> BD9 -> DB12 -> P7 -> Depot = 152 km

➢ Group 2: Main Road Route 2309. Depot, P6, P8, P9, BD11.

Table 6. Distance matrix in the context of the Traveling Salesman Problem (TSP) Group 2.



Distance (Km.)					
From \ To	Depot	P6	P8	P9	BD11
Depot	0	17	13	17	77
P6	17	0	4	3	87
P8	13	4	0	7	39
P9	17	3	7	0	40
BD11	77	87	39	40	0

Table 7. Distance Matrix Calculate" in the context of the Traveling Salesman Problem (TSP) Group 2.

No.	Point Start and End	Distance	Km.
1	Depot -> P6 -> P8 -> P9 -> BD11 -> Depot	17 + 4 + 7 + 40 + 77	145 Km.
2	Depot -> P6 -> P8 -> BD11 -> P9 -> Depot	17 + 4 + 39 + 40 + 17	117 Km.
3	Depot -> P6 -> P9 -> P8 -> BD11 -> Depot	17 + 3 + 7 + 39 + 77	143 Km.
4	Depot -> P6 -> P9 -> BD11 -> P8 -> Depot	17 + 3 + 40 + 39 + 13	112 Km.
5	Depot -> P8 -> BD11 -> P9 -> P6 -> Depot	13 + 39 + 40 + 3 + 17	112 Km.
6	Depot -> P6 -> BD11 -> P8 -> P9 -> Depot	17 + 87 + 39 + 7 + 17	167 Km.
7	Depot -> P6 -> BD11 -> P9 -> P8 -> Depot	17 + 87 + 40 + 7 + 13	164 Km.
19	Depot -> BD11 -> P6 -> P8 -> P9 -> Depot	77 + 87 + 4 + 7 + 17	192 Km.
20	Depot -> BD11 -> P6 -> P9 -> P8 -> Depot	77 + 87 + 3 + 7 + 13	187 Km.
21	Depot -> BD11 -> P8 -> P6 -> P9 -> Depot	77 + 39 + 4 + 3 + 17	140 Km.
22	Depot -> BD11 -> P8 -> P9 -> P6 -> Depot	77 + 39 + 7 + 3 + 17	143 Km.
23	Depot -> BD11 -> P9 -> P6 -> P8 -> Depot	77 + 40 + 3 + 4 + 13	137 Km.
24	Depot -> BD11 -> P9 -> P8 -> P6 -> Depot	77 + 40 + 7 + 4 + 17	145 Km.

(a)

```python
import numpy as np
import random
distance_matrix = np.array([
    [0, 10, 40, 44, 46, 33],
    [10, 0, 38, 42, 44, 27],
    [40, 38, 0, 17, 19, 51],
    [44, 42, 17, 0, 2, 54],
    [46, 44, 19, 2, 0, 56],
    [33, 27, 51, 54, 56, 0]
])
def calculate_total_distance(route, distance_matrix):
    total_distance = 0
    for i in range(len(route) - 1):
        total_distance += distance_matrix[route[i], route[i + 1]]
    return total_distance

      Nearest Neighbor Heuristic (NNH)
def nearest_neighbor(route, distance_matrix):
    unvisited = set(route)
    current = route[0]
    new_route = [current]
    unvisited.remove(current)
    while unvisited:
        next_city = min(unvisited, key=lambda city: distance_matrix[current, city])
        new_route.append(next_city)
        unvisited.remove(next_city)
        current = next_city
    new_route.append(route[0])
    return new_route
```

(b)

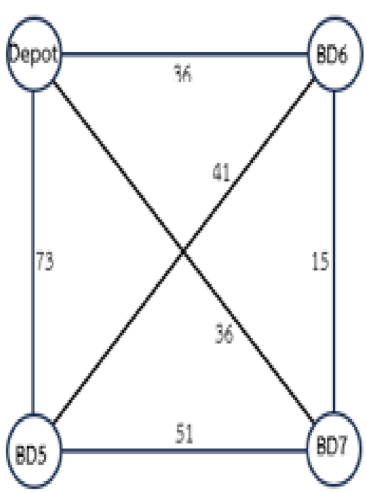
```python
    current_route = route
    current_distance = calculate_total_distance(current_route, distance_matrix)
    best_route = current_route
    best_distance = current_distance
    temp = initial_temp

    for _ in range(max_iterations):
        new_route = swap_two_cities(current_route)
        new_distance = calculate_total_distance(new_route, distance_matrix)
        if new_distance < current_distance or random.random() < np.exp((current_distance -
            current_route = new_route
            current_distance = new_distance
            if current_distance < best_distance:
                best_route = current_route
                best_distance = current_distance
        temp *= cooling_rate

    return best_route, best_distance

initial_route = [0, 1, 2, 3, 4, 5, 0]

nnh_route = nearest_neighbor(initial_route, distance_matrix)
best_route, best_distance = simulated_annealing(nnh_route, distance_matrix, initial_temp=1

print(best_route)
print(best_distance)
```

Figure 3. (a) Demonstration of Using Function Nearest Neighbor Heuristic (NNH). (b) Function Simulated Annealing (SA) Group 2.

From the Calculation of All 24 Routes
The optimal route for Group 2 is 112 Km.

- Depot -> P6 -> P9 -> BD11 -> P8 -> Depot = 112 Km.
- Depot -> P8 -> BD11 -> P9 -> P6 -> Depot = 112 Km.

Table 8. Distance matrix in the context of the Traveling Salesman Problem (TSP) Group 3



Distance (Km.)				
From \ To	**Depot**	**BD5**	**BD6**	**BD7**
Depot	0	73	36	36
BD5	73	0	41	51
BD6	36	41	0	15
BD7	36	51	15	0

Table 9. Distance matrix Calculate" in the context of the Traveling Salesman Problem (TSP) Group 3.

No.	Point Start and End	Distance	Km.
1	Depot -> BD5 -> BD6 -> BD7 -> Depot	73 + 41 + 15 + 36	165 Km.
2	Depot -> BD5 -> BD7 -> BD6 -> Depot	73 + 51 + 15 + 36	175 Km.
3	Depot -> BD6 -> BD5 -> BD7 -> Depot	36 + 41 + 15 + 36	128 Km.
4	Depot -> BD6 -> BD7 -> BD5 -> Depot	36 + 51 + 41 + 73	201 Km.
5	Depot -> BD7 -> BD5 -> BD6 -> Depot	36 + 51 + 41 + 15	143 Km.
6	Depot -> BD7 -> BD6 -> BD5 -> Depot	36 + 51 + 15 + 41	143 Km.

Group 3 Main Road Route 24 (Upward Route) Depot, BD5, BD6, BD7

(a)

```
import random
import math

# ข้อมูลระยะทางระหว่างจุดต่างๆ
distance_matrix = {
    'Depot': {'Depot': 0, 'BD5': 73, 'BD6': 36, 'BD7': 36},
    'BD5': {'Depot': 73, 'BD5': 0, 'BD6': 41, 'BD7': 51},
    'BD6': {'Depot': 36, 'BD5': 41, 'BD6': 0, 'BD7': 15},
    'BD7': {'Depot': 36, 'BD5': 51, 'BD6': 15, 'BD7': 0}
}

def calculate_total_distance(route, distance_matrix):
    total_distance = 0
    for i in range(len(route) - 1):
        total_distance += distance_matrix[route[i]][route[i+1]]
    return total_distance

def nearest_neighbor_heuristic(start, distance_matrix):
    unvisited = list(distance_matrix.keys())
    unvisited.remove(start)
    route = [start]
    current_location = start

    while unvisited:
        next_location = min(unvisited, key=lambda loc: distance_matrix[current_location][l
        route.append(next_location)
        unvisited.remove(next_location)
        current_location = next_location

    route.append(start)  # กลับไปที่เริ่มต้น
    return route
```

(b)

```
def simulated_annealing(route, distance_matrix, initial_temp, cooling_rate, num_iterations
    current_route = route
    current_distance = calculate_total_distance(current_route, distance_matrix)
    best_route = list(current_route)
    best_distance = current_distance

    temp = initial_temp

    for iteration in range(num_iterations):
        i, k = sorted(random.sample(range(1, len(route) - 1), 2))
        new_route = swap_2opt(current_route, i, k)
        new_distance = calculate_total_distance(new_route, distance_matrix)

        if new_distance < current_distance or random.uniform(0, 1) < math.exp((current_dis
            current_route = new_route
            current_distance = new_distance

            if current_distance < best_distance:
                best_route = current_route
                best_distance = current_distance

        temp *= cooling_rate

    return best_route, best_distance
```

Figure 4. (a) Demonstration of Using Function Nearest Neighbor Heuristic (NNH). (b) Function Simulated Annealing (SA) Group 3.

Based on the calculation of all 6 routes,
The best route for Group 3 is 143 km

- Depot -> BD7 -> BD6 -> BD5 -> Depot = 143 km
- Depot -> BD7 -> BD5 -> BD6 -> Depot = 143 km

The calculation results show that the routes obtained from using Nearest Neighbor Heuristic (NNH) and Simulated Annealing (SA) align with the provided data, resulting in the best and most suitable total distances for operations. Therefore, these are the best routes for each group, helping to reduce total distance and energy usage.

- Route 1: Depot -> P7 -> DB12 -> BD10 -> BD9 -> BD8 -> Depot = 152 km
- Route 2: Depot -> P6 -> P9 -> BD11 -> P8 -> Depot = 112 km
- Route 3: Depot -> BD6 -> BD5 -> BD7 -> Depot = 143 km

Improving these routes will help reduce the total distance and energy usage for transporting food to the farms efficiently across all three routes. The total distance is 407 km per round, running 3 rounds per day, resulting in 1,221 km/day.

Table 10. New Food Transportation Routes

Route 1	Depot	P7	BD12	BD10	BD9	BD8	Depot	Total Km.	Total Hr.
	0	10	27	56	2	17	40	152	1Hr. 43 min
Route 2	Depot	P6	P9	BD11	BD8	Depot	Total Km.	Total Hr.	
	0	17	3	40	39	13	112	2Hr. 04 min.	
Route 3	Depot	BD7	BD6	BD5	Depot	Total Km.	Total Hr.		
	0	36	51	15	41	143	1Hr. 50 min.		

Route 1 : Start from Depot -> P7 -> DB12 -> BD10 -> BD9 -> BD8 -> Depot.
: Total distance: 152 km. Travel time: 1 hour 43 minutes.
Route 2 : Start from Depot -> P6 -> P9 -> BD11 -> P8 -> Depot.
: Total distance: 112 km. Travel time: 2 hours 4 minutes.
Route 3 : Start from Depot -> BD6 -> BD5 -> BD7 -> Depot
: Total distance: 143 km. Travel time: 1 hour 50 minutes.

Summary of Total Distances.
- Total distance for 3 routes: 407 km per round.
- Daily operation: 3 rounds per day, resulting in a total of 1,221 km per day.

5.2 Graphical Results
Map Illustration of the New Route Plan for Food Transportation
The new route plan for food transportation is designed to optimize efficiency and reduce total transportation distance, reducing the routes from four to three. The routes are color-coded as follows:

- Yellow Route: Covers farms in the upper part of the map.
- Blue Route: Covers farms in the lower-left area of the map.
- Red Route: Covers farms in the lower-right area of the map.

The Cargill Breeder Office CMK serves as the central starting point, connecting all three routes. This centralization facilitates efficient management and planning of transportation.
Applying the Traveling Salesman Problem (TSP) theory to route planning significantly reduces the total daily transportation distance. This reduction leads to lower transportation costs and decreased energy consumption.
Driver management has been optimized, providing drivers with scheduled weekly days off, reducing overtime, and increasing their rest time. These route improvements are expected to enhance food transportation efficiency, reduce costs, and create a balanced workload for drivers in the farm network

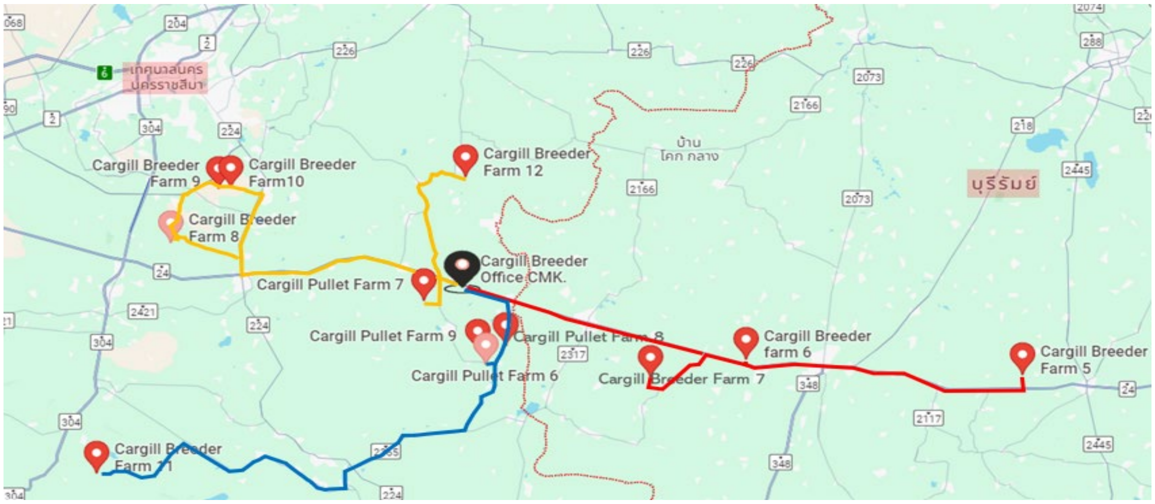


Figure 5. The New routes for transporting food to the farm consist of 3 routes

The optimization of food transportation routes from four to three is achieved by applying the Traveling Salesman Problem (TSP) as the main planning approach. The new routes are divided into three main routes as follows

Yellow Route: Covers farms in the upper part of the map.
Blue Route: Covers farms in the lower-left part of the map.
Red Route: Covers farms in the lower-right part of the map.
All routes start from the Cargill Breeder Office CMK, which serves as the central hub.

The application of TSP significantly reduces the total daily transportation distance. Preliminary analysis indicates a reduction in the total transportation distance from 1,767 Km./day in scenario 1 to 1,221 Km./day in scenario 2. Additionally, reducing the transportation distance decreases energy consumption and operational costs.

Furthermore, a new driver management plan has been implemented to enhance efficiency. This involves scheduling work and rest days appropriately, ensuring drivers have sufficient rest and reducing overtime. This management approach reduces driver fatigue and increases the efficiency of food transportation within the farm network.
These improvements not only enhance the efficiency of food transportation but also reduce costs and energy consumption. As a result, the farm network can operate more effectively and maintain a balanced workload for the drivers.

5.3 Proposed Improvements

The validation of the proposed food transportation route optimization was conducted by comparing the results of applying the Traveling Salesman Problem (TSP) with the current operations. The total transportation distance per day was significantly reduced from the original 1,767 Km./day in scenario 1 and 1,485 Km./day in scenario 2 to a shorter distance in the new plan. The new driver allocation plan using TSP helps reduce overtime and increase the efficiency of the drivers. With adequate rest, drivers experience less fatigue and can work continuously. Additionally, the new route arrangements reduce energy consumption and operational costs, benefiting the organization.
In real-world testing, the improved routes successfully reduced the total distance and number of transportation rounds as expected. The new routes also decreased transportation time and ensured that drivers had weekly days off, resulting in smoother and more continuous operations.

The results verification included analyzing the drivers' rest days management. It was found that drivers could have regular weekly days off without affecting operations, ensuring uninterrupted food transportation. The verification summary shows that the application of TSP and the new route management enhanced food transportation efficiency by reducing the total distance, minimizing overtime, and optimizing driver allocation. This improvement leads to more balanced and efficient operations for the farm

5.4 Validation

The validation of the effectiveness of applying the Traveling Salesman Problem (TSP) theory to food transportation route planning demonstrated significant improvements in operational efficiency. Specifically, the total daily transportation distance was reduced from 1,767 kilometers in scenario 1 and 1,485 kilometers in scenario 2 to shorter, more optimized distances according to the new plan. This reduction in distance not only minimized fuel consumption and transportation costs but also contributed to a lower carbon footprint.

Furthermore, the new driver management strategy proved to be highly effective. By providing drivers with regular weekly rest days, the strategy helped to mitigate fatigue and reduce the incidence of overtime work. This improvement in driver welfare led to enhanced productivity and a more sustainable workforce. The drivers were able to perform their duties with increased efficiency, leading to smoother and more continuous operations. The implementation of this strategy ensured that the logistics process became more reliable and consistent, thereby improving overall service quality and customer satisfaction

6. Conclusion

Applying the Traveling Salesman Problem (TSP) theory to food transportation route planning enabled a significant reduction in total transportation distance, energy consumption, and operational costs. By optimizing the routes, the total distance traveled by delivery vehicles was substantially decreased. This not only reduced fuel consumption and emissions but also lowered the overall operational costs associated with transportation. The reduction in distance translated directly into financial savings, as less fuel was required, and vehicle wear and tear were minimized, leading to lower maintenance costs.

Furthermore, the implementation of a new driver management approach allowed drivers to have weekly rest days without affecting the overall operations. This strategy improved driver welfare by ensuring they had adequate rest, which reduced fatigue and the risk of accidents. Well-rested drivers are more alert and efficient, contributing to safer and more reliable transportation operations. The regular rest days also helped in retaining drivers by improving job satisfaction, thus reducing turnover rates and the costs associated with hiring and training new drivers.

The combination of optimized routes and improved driver management resulted in more efficient food transportation. The streamlined operations ensured that deliveries were timely and consistent, enhancing the reliability of the service. Reduced expenses and energy use contributed to a more sustainable and eco-friendly operation, aligning with broader environmental goals.

Overall, the integration of TSP with advanced driver management practices enabled the farm network to operate more effectively and balanced. It demonstrated that leveraging mathematical optimization techniques, combined with strategic human resource management, could lead to substantial improvements in operational efficiency. This holistic approach ensured that the benefits were not only economic but also social and environmental, making the transportation system more robust and sustainable in the long term.

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