

SOLUTIONS FOR TRANSPORTATION AND MAINTENANCE SCHEDULING NEEDS: A CASE STUDY OF A FUEL DISTRIBUTION COMPANY IN UTTARADIT PROVINCE

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Abstract

This research focused on the issue of fuel demand management. It proposed scheduling transportation and maintenance of a fuel distribution company and developing a mathematical scheduling model for planning the fuel needs of the substation and automatic gas station for scheduling transportation and maintenance. The researcher developed the program using economical algorithmic heuristics and Ant Colony Optimization (ACO) to solve this problem. The experiment revealed that any problem can find its optimal solution using the developed mathematical scheduling model. They could also schedule transportation and maintenance at the lowest cost. The research compared the results obtained before and after the process. The researcher revealed that the efficiency percentage values were 49 for July 2022 and January 2023, 39 for August 2022 and February 2023, 42 for September 2022 and March 2023, 38 for October 2022 and April 2023, 35 for November 2022 and May 2023, and 31 for December 2022 and June 2023, respectively. Therefore, this research achieved its objectives.

Keywords: Demand Problem; Fuel Transportation Costs; Optimal Transportation Scheduling; Program Development

Introduction

Business operations nowadays are highly competitive environments (Fedele and Formisano, 2022; Song *et al.*, 2024). Every business finds principles or methods of the management theorem that enable the businesses to create strengths and increase the competitive potential to be superior to its competitors (Veile *et al.*, 2022). For-profit and the highest customer satisfaction are important.

Applying mathematical and statistical methods for planning and decision-making in both short-term and long-term operations by developing a program using mathematical principles is one tool that helps to get production information and inventory management, including managing sales to be most efficient. Therefore, using mathematical methods, statistical methods and how to find answers by

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using heuristics plays an important role in the management of a business, which is an effective method. This results in low production costs per unit. (Deb and Gupta, 2023). Gupta and Deb follow are labour costs, time costs, and lower management costs as well. The fuel distribution company used in this research was established to meet the needs of customers in Uttaradit Province and Sukhothai Province, an industrial area including sugar production factories, factories producing electricity from waste materials; bagasse, and the rice processing industry. Moreover, there is more than 85 percent of the agricultural processing industry in these two provinces. The company is 20 kilometers from the city. The company operates energy businesses selling fuel, gas stations, electric charging stations, petrol stations, and automatic oil dispensers. The company has a working capital of more than 150 million baht annually. The company has a problem with using fuel for transportation between the refinery and the company's distribution points. In addition, the company has sales of more than 1,152,000 liters of fuel per year. The company has large fuel transport vehicles that pick up oil from the refinery or fuel distribution centers in other provinces. There are medium-sized transport vehicles and more than 10 small transport vehicles, which have different transport sizes, such as 12,000 liters, 4,000 liters, 3,000 liters, and 1,200 liters. There are more than 50 transport trips per week, including transport from refineries or fuel distribution centers to substations and automatic fuel containers with various sizes of transport vehicles, the need for fuel use and transportation to sub-fuel stations, and automatic oil dispensers together with maintenance. The survey results found that there are more than 30 automatic fuel dispensers, both franchised and the company's automatic fuel dispensers, spread out in various places in Uttaradit Province and Sukhothai Province. According to the above problems, the company did not have a plan for the demand for the fuel that would be used each week and each month. It was just using the expertise of employees from looking at the fuel usage rate of the station, digestive oil, automatic fuel dispensers, and various distribution units, thus making sub-fuel stations. There aren't enough automatic machines to sell at a certain time. This causes the loss of customers and sales opportunities. The company does not plan for the routes of vehicles to refuel and systematic maintenance. This problem makes the company not know the true costs in the distribution of fuel substations (Kuyffer *et al.*, 2023) that are spread out

over the areas that must be filled with fuel at the substation oil storage tanks and tanks packed in automatic cabinets. It had to wait for distribution once a week. Entering the automatic cabinet or substation requires maintenance of the fuel cabinet in the substation and automatic cabinets as well, such as changing parts, maintenance, cleaning, fastening, and changing parts according to the usage cycle or else. Maintenance has a limited period at each workstation that must be maintained under the maintenance conditions of Preventive Maintenance (PM) (Finkelstein *et al.*, 2023). The company plans to change spare parts according to the period, periodic maintenance planning (Vanderschueren *et al.*, 2023), and clean electronic systems with the automatic fuel dispenser system. From studying data in 2022, there was a cost of transporting fuel and refueling tanks of 1,850,500 baht, maintenance costs, and changing spare parts of 970,000 baht, a total cost of 2,820,500 baht. The research aimed to develop a mathematical scheduling model. (Grishin *et al.*, 2022) in planning fuel needs of substations, the automatic oil dispensers and the scheduling of transportation and maintenance.

Therefore, the research has determined a strategy to reduce costs by focusing on efficient route planning and improving the maintenance process to make it more appropriate. The challenge of this problem differs from previous research in that it involves a maintenance schedule that takes into account the need to refuel the automatic fuel dispenser, thereby requiring a more complex solution. Through research, the program has been developed by using the economical algorithm heuristics and the Ant Colony Optimization (ACO) (Ahmed and Yousefikhoshbakht, 2022; Siping, 2023) methods to find answers to this problem. The program was developed using C++ combined (Sui *et al.*, 2023), a collaborative search for answers using heuristics and finding linear schedule answers. The research collected data on demand, transportation, and maintenance scheduling. The data before the research was collected in 2022, July to December 2022, for 6 months, and after the research, during the research period in 2023, January to June 2023, for 6 months, to compare the costs from this research. The researcher found that there were no seasonal factors affecting the demand and malfunction of automatic fuel dispensers during the time period prior to the research. Therefore, the researcher selected a time period that reflects the clarity between the research period and the collected data.

Multi-Compartment Vehicle Routing Problem (MCVRP)

It generally refers to managing transportation problems (Vehicle Routing Problem, VRP) (Sriburum *et al.*, 2022; Elatar *et al.*, 2023; Rezaei *et al.*, 2023; Song *et al.*, 2024). Transportation routing is the assignment of vehicles to travel to pick up or send products to customers according to the quantity demanded by customers who order the amount of cargo capacity in vehicles used for transporting goods that have a limited capacity. Vehicles will begin their journey to deliver the goods and return to the original distribution center. The VRP problem (Ahmed and Yousefikhoshbakht, 2022) is an important problem at the logistics level in the business sector and transportation management industry. If there is a low cost, it will create more competitiveness in the market. Every country gives importance to this VRP transportation problem as an NP-hard problem (Siping, 2023; Tiwari and Sharma, 2023). The larger the problem size, the more complex the solution becomes. From the literature review, some researchers brought problems to be solved by using various methods as follows:

Vieira *et al.* (2023) researched vehicle route planning that took into account the main issues related to the supply chain in the transport environment with complex problems. NP-hard models and meta-heuristics are used to solve problems in the automotive industry, and vehicle routing problems (VRP) are considered in this research as well.

Soares *et al.* (2023) researched the vehicle routing problem (VRP) in which a business sector faces specific transportation needs, and VRP is becoming more complex. A comprehensive literature review will identify gaps and future research opportunities in the field of VRP with synchronization as shown in Figure 1.

Scheduling problems are an important and common problem in the transportation management industry and vehicle routing because the business sector or an industrial factory needs the most efficient demand plan to operate production under regulations and many different limitations in production and transportation, (Davatgari *et al.*, 2024) such as operating hours of machines and vehicles, working hours of human resources, etc., therefore, the scheduling work by choosing to arrange an order of work to enter the work before or after appropriately (Chaouch *et al.*, 2021, Frisch *et al.*, 2021) in the transportation will be completed on schedule according to the delivery date to the customer. This is what each establishment expects from this table (Cordone and Holsteins, 2019, Phuk-in, 2024b).

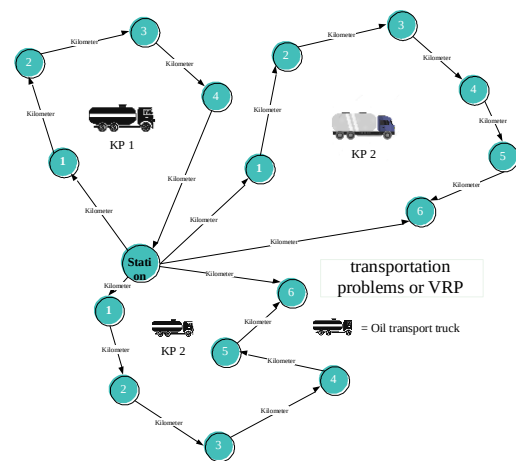


Figure 1. Visual representation of the proposed problem aspect classification schema Scheduling problem

Preventive Maintenance (PM)

Over the past several decades, preventive maintenance has become a key concept in improving production. Most modern manufacturing companies have implemented these improvement programs as business fit. The general foundation of PM is a focus on human resources and machinery. This will affect the efficiency of work, especially the supporting role of employee engagement practices in companies (Frisch *et al.*, 2021; Finkelstein *et al.*, 2023; Kuyffer *et al.*, 2023).

Materials and Methods

Study of fuel transportation problems of a fuel distribution company in Uttaradit province as a case study: The business process involves the sale of oil (petroleum), which is distributed in Uttaradit and Sukhothai provinces. It is the location of a sugar production factory, a power plant, and the agricultural industrial sector in the area. More than 30 percent of sales are carried out with transport vehicles. In addition, they are sold at two large gas stations with sales of 30 percent per year. There are more than 30 automatic vending machines in communities spread throughout the province and outside the province. Sales are 40 percent. Demand and transportation issues are important factors for this company, whether it is transporting large transport vehicles or transporting from the company to the refinery more than 2 times a week. Transporting oil to sub-branch oil stations is done once a week with a vehicle. Medium-sized transport and transportation with small cars were transported to 30 automatic fuel tanks, transported 1-2 times

a week according to demand. Such transportation is a problem for the company with high costs incurred. As mentioned above, whether it is the cost of transporting fuel, refueling at substations, or automatic fuel dispensers, each visit involves maintenance and replacement of parts according to the preventive maintenance method.

Transportation costs of small, medium, and large vehicles

Transport vehicles that enter the area to refuel for sale at the cost of 1,850,500 baht. This cost arises from labor costs. The cost of fuel used in transportation varies with transportation distance.

Costs of maintenance and replacement of parts

Business operations have a cost of 79,708 baht. Transportation uses different vehicles with compartments in the transport vehicle; for example, transporting fuel from the company to the refinery uses a large vehicle with a capacity of 18,000 liters. A medium-sized vehicle with a capacity of 8,000 liters is used for fuel transportation to the substation. Fuel transportation to the vending machine uses a small vehicle with a capacity of 1,200 liters. Maintenance costs and spare parts exchange are therefore costs that vary with the distance traveled of transportation for each trip.

Maintenance of gasoline substations and automatic oil dispenser

It is the cost of maintenance and replacement of spare parts for 970,000 baht per year, arising from changing spare parts, repairs, and replacing sensors (sensor system) in the automatic fuel tank and dispenser cabinets in gas substations cleaning. The machine maintenance data will be sent through the Internet of Things (IoT) system for inspection and repair notification. Cleaning with a solution set that has a definite period (minutes) is a cost calculated according to time, labor costs, and spare parts according to the PM method.

Working capital used in business operations of a fuel distribution company in Uttaradit province

In one year, working capital is used equal to 170 million baht per year for raw materials, oil, labor, transportation, maintenance, and management fees. There is an annual tax payment of 1,200,000 baht per year. Cost is an important factor in the insights of this research, which has received favorable cooperation from fuel distribution company operators in Uttaradit Province. This cooperation has enabled this research to effectively reduce costs in various areas, such as fuel demand at fuel stations and vending

machines, as well as maintenance costs appropriately integrated with preventive maintenance (PM) plans.

Development of mathematical Programming models

Solving the problem of oil demand at substations and automatic oil dispensers and transportation scheduling and maintenance of the company are shown as follows:

The researcher brought a solution to the transportation problem of fuel demand at different gas stations, which had different needs. According to the information that was stored and demanded each week, which had an index, parameters, and decision variables as follows:

Indices

i = On-demand oil supply node

j = The node receives fuel on demand.

Parameters

S_i = The maximum amount of fuel supplied by the node

d_i = Fuel demand of the receiving node

C_i = Fuel transportation costs incurred per unit from node i to node j

M_i = Cost of maintaining a transport vehicle varies with the distance of the transport i .

O_i = Cost of gasoline expenses varies with distance i .

L_i = Labor costs for transporting and maintaining node i

MT_i = Cost of replacing spare parts according to the replacement cycle of maintenance of gas stations and automatic machines at i

Decision variables

X_{ij} = The amount of cost of transporting fuel from node i to node j

P_{ij} = Cost of planned maintenance time for substation maintenance, and automatic fuel dispenser at i to node j

Objective function

$$\text{Min } \sum_{i=1}^m \sum_{j=1}^n C_{ij} X_{ij} \quad (1)$$

Subject to

$$\sum_{j=1}^n X_{ij} \leq S_i \quad (\forall i = 1, 2, 3, \dots, m) \quad (2)$$

$$\sum_{i=1}^m X_{ij} \geq d_i \quad (\forall j = 1, 2, 3, \dots, n) \quad (3)$$

$$C_j = \sum_{i=1}^m X_{ij} [(p_{ij}M_{ij}) + L_{ij} + O_{ij} + MT_{ij}]$$

$$(j = 1,2,3 \dots n) \quad (4)$$

$$X_{ij} \geq 0 \quad (\forall i = 1,2,3 \dots m, j = 1,2,3 \dots n) \quad (5)$$

$$P_{ij} \geq 0 \quad (\forall i = 1,2,3 \dots m, j = 1,2,3 \dots n) \quad (6)$$

The equations and inequalities 1-6 are used in this research and can be explained as follows:

Equation 1 is an objective function to find the costs of transporting oil to the company's substations.

Inequality 2 is a constraint of a total quantity of oil demand that the amount of cost of transporting fuel from node i to node j is less than or equal to the maximum amount of fuel supplied by the node.

Inequality 3 is a constraint of fuel transportation costs incurred per unit from node i to node j that the amount of cost of transporting fuel from node i to node j is greater than or equal to the fuel demand of the receiving node.

Equation 4 is a constraint of fuel transportation costs incurred per unit from node i to node j.

Inequalities 5-6 are the requirements for the solutions to be greater than or equal to 0 and in integers.

To solve the problem, a mathematical schedule model was designed to develop the C++ program. This research has developed a hybrid program (Umam *et al.*, 2022) by using the heuristic method; Saving Algorithm (SA), and Ant Colony Optimization (ACO) (Siping, 2023) to find answers to the problem, i.e., route demand problem, transportation scheduling problem, and maintenance (Lingling *et al.*, 2023) where the developed program has program error checking (Testing and Debugging). There are two steps to checking program errors: checking with the programmer (self-checking) and checking with language translation. Translating is shown in Figure 2.

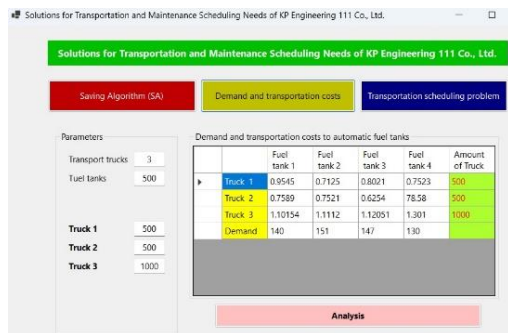


Figure 2. Programs developed to solve research problems

Mathematical scheduling models solve scheduling problems

In solving transportation and maintenance scheduling problems of a fuel distribution company in Uttaradit province, when mathematical models are used to solve demand problems (Dorigo and Stützle, 2009; Banerjee *et al.*, 2023), solving route and scheduling problems. Transportation and maintenance are the next methods. Because resources are limited. The company stipulates that refueling at substations and automatic cabinets, together with maintenance, takes only 1-2 days per week. Therefore, transportation and maintenance schedules must be systematically arranged to deal with this problem (Kuyffer *et al.*, 2023).

The transportation and maintenance scheduling shows perfect binary values (Binary) or 0, 1 if the conditions of the equation are met, as shown in Equations 7 to 13 as follows.

Indices

i = Transportation time and maintenance time of the substation determined from the maintenance plan

j = Transportation vehicles, equipment, and tools used for maintenance from the maintenance plan

k and l = Representing the transportation vehicle Workers who have been given jobs

Parameters

m = The number of sub-fuel stations or automatic oil dispensers

n = The number of tasks

C_{max} = Time to complete all batches

P_i = Time spent doing work at i

C_i = Work completion time at i

X_{ij} = Assigning workstation j to work i

y_{ik} = Assigned to work station k to work at i is 1 and 0 if the binary condition is not met.

Minimize C_{max}

$$C_{i_{max}} \geq C_i \text{ Where } \forall 1 \leq i \leq n \quad (7)$$

$$C_i - P_i \geq 0 \text{ Where } \forall 1 \leq i \leq n \quad (8)$$

$$\sum_{j=1}^j x_{ij} \leq 1 \text{ Where } \forall 1 \leq i \leq n \quad (9)$$

$$C_i - (C_j - P_j) + Y_{ij}M \geq 0 \text{ Where } \forall 1 \leq i, j \leq n \quad (10)$$

$$C_i - (C_j - P_j) - (1 - Y_{ij})M \leq 0 \text{ Where } \forall 1 \leq i, j \leq n \quad (11)$$

$$X_{ik} + X_{jk} \leq (Y_{ij} + Y_{ji})M + 1 \text{ Where } \forall 1 \leq i < j \leq n \text{ and } \forall 1 \leq k \leq m \quad (12)$$

$$X_{ik} + X_{jl} \leq (Y_{ij} + Y_{ji})M + 1 \text{ Where } \forall 1 \leq i < j \leq n \text{ and } \forall 1 \leq k < l \leq m \quad (13)$$

Inequality 7 is the finishing time of the transport batch and maintenance assigned, which is greater than or equal to the time spent on each task.

Inequality 8 is shipping start time and maintenance work; $C_i - P_i$ that is greater than or equal to 0 indicates that no work can be started before time 0.

Inequality 9 is an assigned transportation and maintenance task that can be done only one job at a time, and complete within the specified time.

Inequalities 10 and **11** are the relationships between Y_{ij} with C_i , C_j , and P_i , including transportation and maintenance tasks.

Inequalities 12-13 are assigning job i to transport oil and maintenance for vehicles or agencies, that X_{ik} , which can be done one job at a time, i.e., job i has the vehicle or agency number k work, and the accumulated tasks values are collected for use.

Problems of oil demand for sub-stations and automatic oil

The problem of the research was to collect data on oil demand from gas stations distributed in various areas, where each week had different demand and costs. Those varied with distance. Cost of oil energy used in each transport, labor costs, and maintenance costs of vehicles used for transport. The research took the example of demand and transportation costs for 3×4 automatic fuel tanks. Demand that is less than or equal to 500 liters per vehicle is the number of 3 transport trucks, sources of 4 automatic fuel tanks, and demand less than or equal to 500 liters per vehicle; there was the demand of 4 fuel tanks: 140, 151, 147, and 130 liters, respectively, as shown in Table 1.

Table 1. Example results of analysis of demand and transportation costs to automatic fuel tanks

	1st Fuel tank	2nd Fuel tank	3rd Fuel tank	4th Fuel tank	Quantity ordered
1st Truck	0	151	0	130	281
2nd Truck	140	0	147	0	287
3rd Truck	0	0	0	0	0
Demand	140	151	147	130	

Table 1 shows an example of the results of the analysis of the needs and costs of transportation to automatic fuel tanks. It could be seen firstly that the

first truck will deliver 151 liters of fuel to Tank 2 and 130 liters to Tank 4. Secondly, prepare to load a total of 281 liters of fuel into the second truck that will deliver 140 liters of fuel to Tank 1 and Tank 3 for 147 liters, respectively. Thirdly, prepare to load 287 liters of fuel into the tank, and the third truck had no delivery. The cost incurred from this problem had a minimum value equal to 403.566 baht, which would be the lowest cost used for this problem.

Problems with fuel transportation scheduling methods of a fuel distribution company in Uttaradit province

Transportation of fuel to substations and the automatic fuel dispenser of the company sampled in the 1st week of May 2022. According to a study of the data, a problem with the cost of transporting the dispenser to fill up the tank of the oil transport vehicle to the substation unit, where i represents the substation and the automatic fuel tank, the receiving node is j . The demand obtained from the calculation of Formula 1 must use the saving algorithm to solve the VRP routing problem before the cost can be calculated. This problem found that the oil needs of the automatic vans are 1 to 7 of the first truck. The amount of oil required is 950 litres, which moves into the refuel and maintains the automatic vans shown in Figure 3.

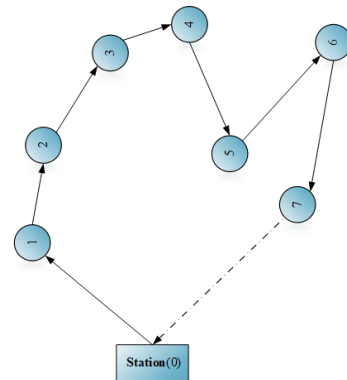


Figure 3. Example of transportation node distance of a petroleum substation and the automatic fuel dispenser of a fuel distribution company in Uttaradit province

From Figure 3, the node distance of the oil substation is shown. The automatic oil dispenser of the company has an automatic oil dispenser node that must be delivered to nodes 1 to 7 together with maintenance and replacement of spare parts shown in Table 2.

Table 2. Automatic dispenser refueling node and maintenance

Nodes	Transportation Costs	Maintenance Costs	Working Time (minutes)
Station -1	101.35	50	20.30
1-2	112.24	54	30.10
2-3	95.21	120	25.64
3-4	97.11	40	28.14
4-6	60.87	25	26.41
6-5	71.25	97	31.25
5-7	78.69	67	27.15
7- Station	50.4	-	-
Total	667.12	936	188.99

According to Table 2, the automatic tank refueling and maintenance nodes, it is found that if this routing method is used for the 1st week of May 2022, there will be transportation costs equal to 667.12 baht, maintenance costs equal to 936 baht, and working time or Mekspan is equal to 188.99 minutes (3.14 hrs). This fuel transportation scheduling is only a solution to the problem of 1 small truck. Therefore, the problem with the company is complex. Then, to solve this difficult NP-hard problem, research uses the heuristics method to solve problems.

Using an economical algorithm to solve the fuel transportation scheduling problem: Saving Algorithm (SA)

Saving algorithms (Lingling *et al.*, 2023; Banerjee *et al.*, 2023; Clarke and Wright, 1964) are used to solve the routing problem. Considering the transport vehicles that will leave the warehouse of the company to deliver fuel to various gas stations, which will be determined by the distance. Packing the size of the transport vehicle to use the lowest distance and cost, which is shown in Equation 14 as follows.

$$S_{ij} = D_{oj} + D_{oi} - D_{ij} \quad (14)$$

Where

O = The starting point for transporting oil to substations i and j.

S_{ij} = Cost savings between fuel delivery points to substations i and j

D_{oj} = Distance between fuel delivery points o and j

D_{oi} = Distance between fuel delivery point o and i

D_{ij} = Distance between fuel delivery points i and j

Steps of problem-solving

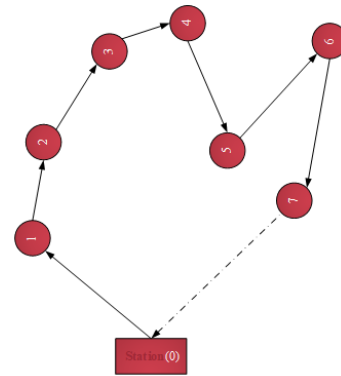
1) Calculate the value of S_{ij} from the oil delivery node from the oil station to the oil substations i and j, which is measured in kilometers.

2) Insertion into substations where there is a need to refuel containers in parallel routes. If the customer link is possible and within the specified conditions, it will be linked to the sub-gasoline station where there is a need to refuel.

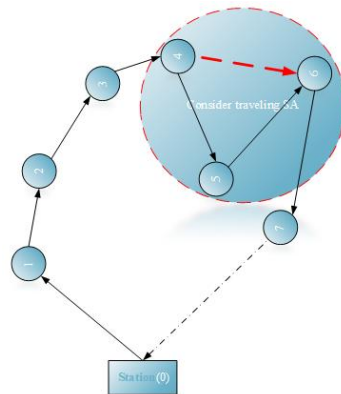
3) Continue to link with substations that need refueling until no new substations can be inserted under the specified conditions.

4) Find an economical route cost. Two conditions are specified: conditions for the feasibility of the route to transport the fuel, and conditions for the amount of packaging that the transport vehicles can carry.

5) When conditions 1-4 are met, use the route information to solve the needs for scheduling fuel transportation and maintenance of the company, as shown in Figures 4(a) and (b).



(a) Before using the Saving Algorithm: SA



(b) Before using the Saving Algorithm: SA

Figure 4. Saving Algorithm and route management

Applying the Ant Colony Optimization method to solve the fuel transportation scheduling problem

The Ant Colony Optimization (ACO) method was first introduced in 1991 by Marco Dorigo and his colleagues. (Dorigo and Stützle, 2009; Zheng *et al.* 2024) It started from observing the intelligent behavior of ants in nature to find the shortest path between food and nest. Ant Colony Optimization method (Zhao *et al.*, 2024; Siping, 2023; Umam *et al.*, 2022; Tayfun and Aysegul, 2022; Phuk-in, 2022a; 2022b; Phuk-in, 2024a; 2024b) is a tool that helps in solving the problem by using the information to create a trail or find answers that are available in 2 types: creating information about random reasoning (Heuristic Information) and the number of traces of Pheromone remaining (Pheromone trail) to help in creating a path shortest of ants as shown in Figure 5.

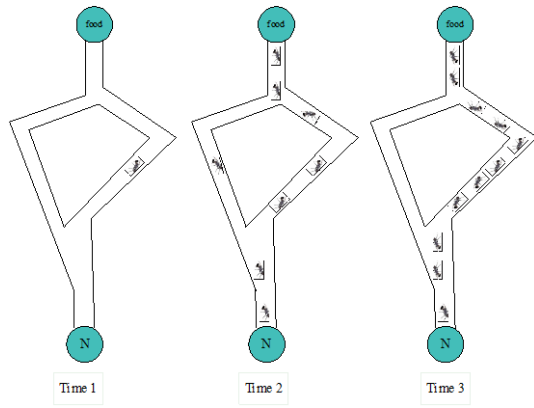


Figure 5. Finding the shortest path between food and nest using the Ant Colony Optimization method

The general workflow of the Ant Colony Optimization method can be separated into 2 main structural parts as follows:

1) Tour Construction: Determining the ant's walking route is the process of creating the route, and it is as follows: Ant K will create an answer by randomly selecting a city or node (city or node) to start with first. The selection of the city to walk to next uses the random proportional rule. The K and while in the city. The next city is at j and will be chosen as in Equation 15.

$$P_{ij}^k = \frac{[\tau_{ij}]^\alpha [\eta_{ij}]^\beta}{\sum_{l \in N_i^k} [\tau_{il}]^\alpha [\eta_{il}]^\beta} \quad \text{if } j \in N_i^k \quad (15)$$

Where $n_{ij} = 1/d_{ij}$ is a reasonably random value of data? d_{ij} : Distance between cities or nodes, α and β are the values used for weighting the pheromone quantity parameter; Pheromone: τ and the weighted values of the data used are reasonably random; Heuristic Information, respectively, and is the number of cities or nodes l is the number of cities or nodes i , and ant k can choose to walk

2). Update of pheromone: Trails increasing and decreasing pheromone trails. After ants = 1, 2, 3, ..., m, where m is the total number of ants that have travelled to every city, they will be able to find the total distance value of m ants that has been obtained. The AS method requires each ant to increase the amount of pheromone and update the pheromone on the path of every ant after travelling through that path. There is also pheromone evaporation along every route. The pheromone evaporation equation is as in equation 15.

$$\tau_{ij} = (1 - \rho)\tau_{ij}, \quad \forall (i, j) \in L \quad (16)$$

When the evaporation rate of the pheromone (ρ) is between $0 < \rho \leq 1$, the evaporation rate of the pheromone, is to avoid the accumulation of excessive amounts of pheromone on the route. Because it will prevent the ants from finding new routes that might be better answers or solutions. In the ant system, when the pheromone has evaporated, the amount of pheromone must be increased; Update the pheromone on the path of each ant that has walked, as in Equation 17.

$$\tau_{ij} = \tau_{ij} + \sum_{k=1}^m \Delta\tau_{ij}^k \quad \forall (i, j) \in L \quad (17)$$

When is the amount of pheromone that the ant will be added to the path that has already been walked? Where is the quantity of the kth ant pheromone to add to the trail? This can be found in Equation 17.

$$\Delta\tau_{ij}^k = \begin{cases} \frac{1}{C^k} & , \text{if } \text{arc}(i, j) \text{ belong to } T^k; \\ 0 & , \text{otherwise;} \end{cases} \quad (18)$$

When C^k is the solution or the total distance that ant k has traveled through the path, which is calculated from the distance between the city or node?

3) Finding answers to transportation needs and costs, and transportation scheduling. The research has developed a C++ program to find answers to the problems of demand and transportation costs by using the nodes of the gas station and the automatic fuel dispenser. It is the route that Ant K will travel with the lowest cost in each route, and finding the cost of scheduling each task. Equation 15 is used to randomly select nodes. Using the working time of each job (Processing times) as the heuristic information value, the heuristic information value obtained in each job will be multiplied by the pheromone value (τ_{ij}), which has been set to have an initial

pheromone value of 1 before being used to calculate the probability value (P_{ij}) to be used in randomly selecting the first job to be walked. By using the probability values to divide the boxes with the sum of every box being 1 is also known as the Roulette wheel, then randomly selects the first task to be moved from one spin of the wheel. The program works with the following steps:

Step 1: Set parameters, conditions, and starting pheromones for finding answers to both demand problems and transportation costs. The transport scheduling consists of the number of ants m used, and the number of cycles t used to find the value and determine the values of α , β , and ρ .

Step 2: Create a pheromone matrix to store or reduce pheromone values in the ant's walking path.

Step 3: Release $k = 1, 2, 3, \dots, m$ ants specified in the first step from the starting point.

Step 4: Create a default answer using word search to find the answers that have a narrow nature (local search) by randomly drawing from a roulette wheel and then randomizing nodes or tasks with probability shown in Figure 6.

Step 5: Improve the path of the ants who created the path. The total distance is the lowest 10% of the total number of ants in the next round.

Step 6: Adjust the pheromone values broadly to find the answer in a new round.

Step 7: Record the appropriate answer in the Pheromone Matrix and use it as a solution in the next round.

Step 8: Check the conditions for stopping. When it is found that the appropriate answer has been obtained, it will stop searching, or what is set in step 1. But if it's still not suitable, it will go back to step 3.

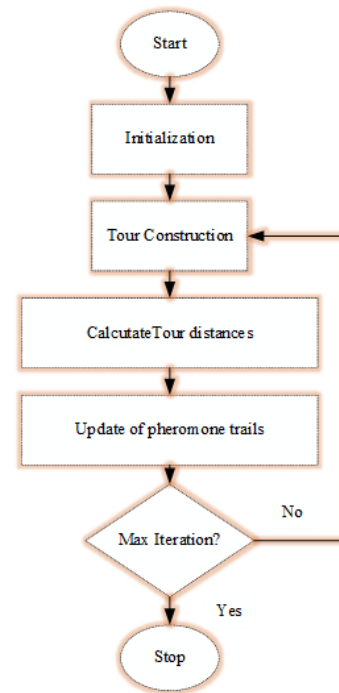


Figure 6. Workflow of Ant Colony Optimization Method: ACO

Results and Discussion

In this research, the objective of the experiment was divided into 2 experiments. The first experiment was to find out the demand and cost of transportation to the oil substation and automatic oil dispenser by using a mathematical schedule model. It is by developing a program to use the Saving Algorithm (SA) to solve the fuel transport scheduling problem and use the Ant Colony Optimization (ACO) method to find integrated answers. The second experiment was to schedule the transportation of fuel to the substation and the automatic fuel dispenser of the company by comparing the lowest costs and off-duty time of the minimal set of transportation and maintenance obtained from this method. Additionally, each experiment was tested on a computer with a 2.80 GHz central processing unit (CPU) and 8 GB of memory (RAM) running Windows 11, 64-bit, Gen Intel(R) Core (TM) i7 operating system. -1165G7.

The research designed a factorial 2^3 experiment to test the optimal parameters of the Ant Colony Optimization method (ACO) to optimize the parameters that divide the factorial effect into 2 levels: low (0) and high (1). The 5 factors with low and high levels in this research consist of the ant population (100/200), the pheromone; τ (0.5/1), the evaporation rate; ρ (0.01/0.02), α parameter (2.5/5), and parameter (2/4). The testing problem sizes of 7×3 and 30×5 are both 32 experiments, and to optimize parameters where the ant population is 200, pheromone starts at 1, the evaporation rate is 0.02, α is 5, and β is 20, respectively.

Results of the experiment on the problem of demand and transportation costs

For the problem of demand and transportation costs of the company in this research. Data has been collected and analyzed from real companies. Because there are several substation nodes, the company's automatic fuel dispenser has a lot, and for ease of testing the accuracy of the mathematical schedule model before initial processing. The researcher divided the problem of demand and transportation costs into 3 types by considering the number of sub-fuel stations. The automatic fuel dispenser is the company's fuel station and dispenser. It is a big problem. There are 1-30 sub-fuel stations, 30 automatic fuel dispensers, and 10 franchised automatic dispensers, which have different weekly needs, as shown in Table 3.

The problem table was used to analyze the transportation needs and costs of the company using mathematical schedule simulation methods together

with the developed program. It is a programming language with a statically typed language structure and uses the Saving Algorithm (SA) and Ant Colony Optimization (ACO) in searching for random answers to find the answer value at the lowest cost. In small, medium, and large problems, the program can find the most appropriate value (optimal solution) for every problem. The results are shown in Table 4.

Table 4 shows the finding answers to the needs and transportation costs of the company in the lowest cost that occurs in all problems, such as the Small 2 problem has a low cost. The highest is equal to 1,214.50 baht, and the program takes 0.131 seconds to process. The Medium 2 problem has the lowest cost, equal to 2,960.51 baht, and the program takes 0.212 seconds to process. According to the results, it occurs in finding costs from the process of researching needs and the lowest transportation costs. Some results occur at an acceptable level in the developed system, which is from the beginning. Experience is used to determine routes based on the expertise of employees. Costs that are not collected and are not known whether they are high or low are the costs of each trip, i.e., vehicle usage costs, labor costs, etc.

Experimental results of transportation and maintenance scheduling

This research applies a method for scheduling fuel transportation and maintenance. These results are in the same program to analyze transportation and maintenance scheduling. In this company, fuel transportation to substations has been planned, and the company's automatic fuel dispenser only 2 days a week. Scheduling is, therefore, important due to limited labor and vehicle resources. So the results of transportation scheduling and maintenance of oil tanks in petrol stations from transporting fuel to substations and the company's automatic fuel dispenser are developed programs that can analyze the results shown in Table 5.

Table 3. Problems of transportation demand and costs

Problem Size	No: of nodes	No: of fuel trucks	Fuel Demand
Small 1	7	3	>500
Small 2	8	2	>450
Small 3	12	3	>780
Medium 1	15	3	>950
Medium 2	20	4	>1,000
Large	30	5	Unlimited

Table 4. Finding answers to transportation needs and costs of a fuel distribution company in Uttaradit province

Problems	Problem Size	Minimum Transportation Costs (Baht)	Processing Time (seconds)	Use of fuel trucks
Small 1	7x3	667.12	0.109	2
Small 2	8x3	1,214.50	0.131	2
Small 3	12x3	1,025.65	0.137	2
Medium 1	15x3	1,299.22	0.245	3
Medium 2	20x4	2,960.51	0.212	3
Large	30x5	14,589.25	5.14	5

Table 5. Transportation and maintenance scheduling of a fuel distribution company in Uttaradit province

Problems	Problem size	Maintenance Costs	Working Period (Minutes)
Small 1	7x3	936.00	188.99
Small 2	8x3	2,547.23	195.78
Small 3	12x3	2,879.63	215.14
Medium 1	15x3	2,987.47	258.87
Medium 2	20x4	3,645.84	435.87
Large	30x5	15,475.97	789.21

Table 5 shows that the transportation and maintenance scheduling of the company has small problems. It is to find maintenance costs and the working period of maintenance of the fuel substation and the company's automatic fuel dispenser; for example, the Small 3 12×3 problem has a maintenance cost of 2,879.63 baht and a total working time of 215.14 minutes, and the Large 30×5 problem has a maintenance cost of 15,475.97 baht and a total working time of 789.21 minutes, respectively.

Comparison before and after research

According to research on data collection of 2022, before research in July to December 2022 (6 months) and after the research during the research period of 2023, January to June 2023 (6 months) are used to compare the research results shown as follows.

Table 6 shows that comparisons of the results pre-research cost in July 2022 was 43,257.20 baht, the research cost in January 2023 was 14,589.21 baht with a percentage efficiency increase of 49 percent, the pre-research cost in August 2022 was 42,547.54 baht, research cost in February 2023 was 18,589.20 baht with an efficiency percentage increase of 39 percent, pre-research costs in September 2022 was 52,587.42 baht, research cost in March 2023 was 21,458.54 baht with an efficiency percentage increase of 42 percent, pre-research cost in October 2022 was 53,245.47 baht, research cost in April 2023 was 23,879.14 baht with an efficiency percentage increase of 38 percent, pre-research cost in November 2022 was 44,147.33 baht, research cost in May 2023 was 21,258.14 baht, with an efficiency percentage increased by 35 and pre-research cost in December 2022 was 49,245.21 baht, research costs in June 2023 was 25,514.54 baht with an efficiency percentage increase of 31 percent, respectively. It shows that the average efficiency increased by 39 percent for 6 months. Before the research, the 6-month period had a total cost of 285,030.20 baht, but after the research, the same period's total cost dropped to 125,288.77 baht, representing a reduction of 159,741.43 baht, or 39 percent of the original cost. The success in solving this problem reflects the efficiency of developing a method to solve the problem with a mathematical schedule model and the algorithm used, which shows the difference and effectiveness that occurs with this problem.

Table 6. Comparison of pre-research and post-research costs

Months for comparison	Comparison of needs costs and transportation costs with large-sized (Baht)		Costs Gap (baht)	Percentage of efficiency (%)
	The company pre-research	A new model from the research		
Jul. and Jan.	43,257.20 (Jul. 2022)	14,589.21 (Jan. 2023)	28,668	49%
Aug. and Feb.	42,547.54 (Aug.2022)	18,589.20 (Feb. 2023)	23,958	39%
Sep. and Mar.	52,587.42 (Sep. 2022)	21,458.54 (Mar. 2023)	31,129	42%
Oct. and Apr.	53,245.47 (Oct. 2022)	23,879.14 (Apr. 2023)	29,366	38%
Nov. and May	44,147.33 (Nov. 2022)	21,258.14 (Mar. 2023)	22,889	35%
Dec. and Jun.	49,245.21 (Dec. 2022)	25,514.54 (Jun. 2023)	23,731	31%

Conclusions

This research took the problems of a fuel distribution company in Uttaradit province, finding problems in managing demand and transportation costs and proper transportation scheduling. The objectives were to develop a mathematical scheduling model for planning fuel demand at substations and automatic gas stations and apply heuristics, the Saving Algorithm (SA), and Ant Colony Optimization (ACO) to solve the problem, which was under limited resources, including the cost requirements of the substation unit and the lowest automatic fuel dispenser, and transportation and maintenance scheduling costs incurred to get the least amount of time to close work (makespan).

The collection of this research data was obtained by collecting distance, time, and cost of transportation routes; maintenance cost of using vehicles; and labor costs for each trip. There was a list of transport items that must be carried out each week and several maintenances, including various related regulations. The problem formulation was divided into 3 sizes: small-sized problems, medium-sized problems, and large-sized problems.

The results of the experiment found that the developed mathematical scheduling model was able to be used to find the answer to the fuel demand of the substations and the most suitable automatic fuel dispensers for every problem within a good period. Hence, scheduling in the same program could also be scheduled at the lowest cost, and transportation resources and labor in transportation could be used with full efficiency. Moreover, this research compared the results between the pre-research costs and the research costs for 6 months. The results of the total efficiency increased by an average of 39 percent, causing the company to use transportation resources and schedule transportation and maintenance with maximum efficiency from this research. The data analysis and comparison reveal that both the mathematical scheduling model and the algorithm can effectively reduce time and cost, making them suitable for addressing demand and scheduling issues. The limitation of this research is the skills of maintenance personnel, which need to be further developed through training in preventive maintenance (PM) because the spare parts used are automatic and electronic, resulting in the current maintenance process taking longer than it should.

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