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Research article

Two-stage capacitated vehicle routing problem for transportation of cherry tomatoes: community enterprise case study in Mae Chui, Thailand

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Abstract

Importance of the work: Routing is one of the important transportation problems in agriculture. Community enterprises are centers that pick up products, such as cherry tomatoes, from farms and forward them on to retailers.

Objectives: To propose two heuristic algorithms to minimize the transportation cost and suggest practical routes.

Materials and Methods: The K-mean machine learning method was applied to clusters of tomato farms using the Weka software. Mixed integer linear programming and proposed heuristic algorithms were applied to solve the problem using the OpenSolver module added to Microsoft Excel. Transportation of cherry tomatoes by the Mae Chui community enterprise was used as a case study.

Results: Based on the results from K-mean clustering, cases 1–5 were clustered into 5 groups while cases 6–7 were clustered into 13 groups. Based on the experimental results from the various scenarios involving productivity, number of trucks and more distant regions, the proposed heuristic algorithms provided a 0.44–2.42% reduction in the total distance and a 0.60–2.58% reduction in the fuel cost for the first stage of transportation. The practical implications were discussed .

Main finding: The proposed heuristic algorithms improved slightly on the existing method, with the findings contributing to operations research information. A practical route was recommended for the transportation of cherry tomatoes in the case study involving the Mae Chui community enterprise.

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Introduction

Due to geographical advantages, agriculture is a major land use in Thailand, with 52% of the land (approximately 51 million ha) being suitable for agriculture (Statista Research Department, 2024). Various kinds of agricultural products, such as rice, rubber and other major crops, are exported to other countries as well as providing ample resources for the domestic population. One important agricultural product is cherry tomatoes that grow very well in the winter season, with reduced production in summer and autumn because of unsuitable temperatures, humidity and pests (Tanyanurak et al., 2022). This leads to lower profits in these two seasons. Therefore, some farmers have addressed this problem by forming a community enterprise to increase their combined competitive advantage. In addition to strengthening competitiveness, operational costs should also be reduced.

One of the major operational costs is transportation (Ongkunaruk and Piyakarn, 2011). In the supply chain, the community enterprise sends a truck to pick up cherry tomatoes from the farms which then returns to the community depot. This is called the pickup stage. The other stage involves the delivery of the cherry tomatoes to the market which is called the delivery stage.

The classical vehicle routing problem (VRP) was proposed by Dantizg and Ramser (1959), where a vehicle travels from a depot to deliver a product to customers and then returns to the depot. The limitation is vehicle capacity, while each customer has a specific individual demand. So, a route sequence must be determined in order to satisfy all customer demands as well as to minimize the transportation cost.

Pickup CVRP is a variant of the VRP model (Chi and He, 2023), where a truck starts from the depot and travels to pick up the product from suppliers and then travels back to the depot. The truck has limited capacity and the objective of this model is also to minimize the total transportation cost.

VRP with simultaneous pickup and delivery was developed by Lehmann and Winkenbach (2024), where a truck travels from the depot to pick up the product from a customer and then delivers the product to another customer. After finishing the delivery, the truck returns to the depot.

VRP is applied for various applications such as dealing with waste management and agricultural products. In waste management, a garbage truck picks up the garbage when the sensor from the Internet of Things (IoT) sends the signal to the center control (Roy et al., 2022). Subsequently, the route is organized.

Agricultural products involve fresh food that is handled using the cold chain approach to handle perishable goods (Cheng et al., 2024). Therefore, the associated supply chain operations should guarantee the shelf life of the fresh food in conjunction with minimizing operation costs (Govindan et al, 2024).

VRP with a time window (VRPTW) was applied by Wang et al. (2023) to handle the delivery of perishable products, where the demand, the sequence of the route and the time at each origin and destination point are determined in order to maximize the profit. Suraraksa and Shin (2019) combined facility location and VRP using a geographic information system to design the route for the supply of fresh fruit and vegetables using a case study in Bangkok, Thailand, with practical implications identified for the decision maker.

The current research considered a two-stage capacitated vehicle routing problem (CVRP). The first aim of the study was to analyze the current operation involving picking up and delivering cherry tomatoes based on data from the Mae Chui community enterprise. Second, the K-mean method was used to cluster the farms located in the same area and to propose a heuristic algorithm combined with mixed-integer linear programming (MILP) to solve the two-stage CVRP. Finally, managerial insights were suggested for decision makers in the studied enterprise.

Materials and Methods

Data collection

Data were collected covering the transportation of cherry tomatoes from the farm to community enterprise and from the community enterprise to the retailer, as well as regarding the amounts of cherry tomatoes handled, the demand from the retailer, farm supply, and information regarding the community enterprise and markets. This combined information (from 1 May 2023 to 30 September 2023) was based on secondary data provided by the Mae Chui community enterprise. There were 17 cherry tomato farms and 2 markets. Locations were specified based on their latitude and longitude values obtained from Google's web mapping service (google.com/maps) and are presented in Table 6, along with the distances between locations and the depot (which did not exceed 70 km). Goods were transported using the 34 four-wheeled trucks in the Mae Chui community, each having a carrying capacity of 3,000 kg. The fuel consumption rate for this type of truck was assumed to be 14.79 km/L (Tires Bid, 2022). The average diesel fuel price during the study period was (1 May 2023 to 30 September 2023) was THB 31.85/L (Bangchak, 2023).

Current state (AS-IS) mapping

The Mae Chui community enterprise in Nakhon Pathom province, Thailand is an organization of local cherry tomato farmers who have combined their resources to be more competitive in the market. The markets for this community include shopping malls and the fresh-food markets in Nakhon Pathom and Suphan Buri provinces. The current practice for transportation of cherry tomatoes from the farms to community enterprise depot and from there to the markets is as follows.

Step 1: a four-wheeled truck picks up the cherry tomatoes from each farm daily. Working hours are 0900–1600 hours. The amount picked up each day and the distance between the community enterprise and the farm are summarized in Table 1.

Table 1 Amounts picked up by farm and distance between community enterprise depot and farms

Farm	Date	Pickup amount (kg)	Distance (km)
Farm 13	1 May 2023	1,250	43.2
Farm 19	2 May 2023	1,400	40.8
Farm 15	3 May 2023	1,836	40.8
Farm 17	4 May 2023	1,025	43.2
⋮	⋮	⋮	⋮
Farm 41	30 September 2023	1,734	40.0
	Total	204,531	15,986.8

Step 2: at the community enterprise depot, the cherry tomatoes are screened to select only the premium grade to deliver to the market.

Step 3: a four-wheeled truck delivers the cherry tomatoes to a market. Working time is 1700–2200 hours. The demand for each day and distance between the community enterprise depot and the markets are presented in Table 2.

Notably, the operations prior to optimization involved the trucks making single visits to a farm and then returning to the depot without any planning of the route.to benefit from picking up the product from farms in the same locality in the one trip.

currently, the operation process is divided into two stages. The first stage involves picking up the tomatoes from the farms and the second stage then delivers them to the markets. As presented in Table 1 and Fig. 1, a four-wheeled truck collected 1,250 kg of cherry tomatoes from Farm 13 on 1 May 2023, involving a round trip distance of 43.2 km. On 2 July 2023, a truck picked up 1,400 kg of cherry tomatoes in a round trip. This practice was the same for the other days, resulting in a total travelling distance of 15,986.8 km from 1 May 2023 to 30 September 2023.

In the second stage, the cherry tomatoes are transported from the community enterprise depot to the markets. As demonstrated in Table 2 and Fig. 1, a four-wheeled truck delivered 150 kg of cherry tomatoes on 1 May 2023 and 150 kg on 2 May 2023 and so on, resulting in a total travel distance of 17,887.5 km from 1 May 2023 to 30 September 2023.

The weaknesses in this process occur in two aspects. First, the distance travelled resulted in expensive total fuel costs of THB 34,427.29. Second, the community enterprise did not utilize the capacity of the available trucks.

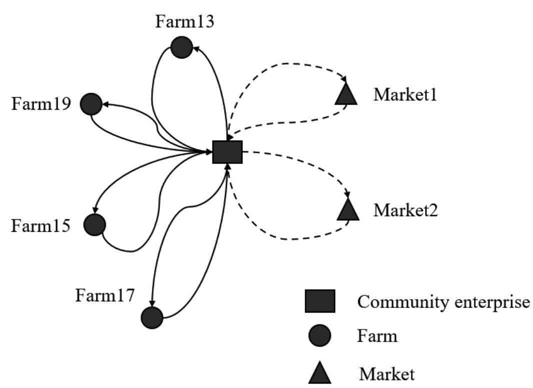

Fig. 1 Current route from cherry tomato farms to Mae Chui community enterprise depot and from depot to markets

Table 2 Market demand and distance between community enterprise depot and markets

Market	Date	Demand (kg)	Distance (km)
Market 1	1 May 2023	150	150
Market 1	3 May 2023	150	150
Market 1	5 May 2023	150	150
Market 2	7 May 2023	450	146
⋮	⋮	⋮	⋮
Market 2	30 September 2023	110	146
	Total	81,950	17,887.5

Proposed method

To address the weaknesses in the current operation, a heuristic algorithm combined with MILP was proposed to search for the optimal route using OpenSolver as an add-in to Microsoft Excel (https://office.microsoft.com/excel). The solver engine was the COIN Branch and Cut solver (CBC), an open-source mixed-integer program solver (linear). The K-mean method was applied to cluster the farms within the same location before the optimization process. The Waikato Environment for Knowledge Analysis (WEKA) collection of machine learning and data analysis free software was used with the K-mean method.

Clustering

K-mean is one of the popular methods used in machine learning. It is an unsupervised algorithm and was used to categorize nearby farms into groups in this research.

The first step involved data pre-processing to apply a consistent naming style for the tomato farm. Then, the farms nearby each other were placed in the same group based on latitude and longitude, which produced the attributes identified in Table 6.

Mathematical modelling

The research was divided into two stages: considering transport from the cherry tomato farms to the community depot and from the community depot to markets. The optimal route was determined using the CVRP model to solve each stage separately. The model is discussed in detail below

Parameters

n = number of locations (1-community, 2, …, n-farms)
d_{ij} = distance from location i to location j
P_i = pickup amount from farm i
C = capacity of each truck

Decision Variables

$x_{ij} = \begin{cases} 1; \text{ if a truck goes from location i to j} \\ 0; \text{ otherwise} \end{cases}$

f_{ij} = the amount of cherry tomatoes in a truck picked up from farms

Objective function $$Min \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} x_{ij} \quad (1)$$

Subject to $$\sum_{j=1}^{n} x_{ij} = 1 \qquad \forall i = 2, 3, \dots, n \quad (2)$$

$$\sum_{j=1}^{n} x_{ji} = 1 \qquad \forall i = 2, 3, \dots, n \quad (3)$$

$$\sum_{j=1}^{n} f_{ji} - \sum_{j=1}^{n} f_{ij} = P_i \qquad \forall i = 2, 3, \dots, n \quad (4)$$

$$0 \le f_{ij} \le C x_{ij} \qquad \forall i, j = 1, 2, \dots, n \quad (5)$$

$$x_{ij} \in \{0, 1\} \qquad \forall i, j = 1, 2, \dots, n \quad (6)$$

The objective was to minimize the total distance, as shown in Equation 1. The sets of constraints in equations (2) and (3) maintain the flow conservation from each location starting from the community enterprise depot to pick up tomatoes from farms and returning to the depot. The constraint in equation (4) ensures that the amount picked up equals the requirement. The constraint in equation (5) makes sure that the load of cherry tomatoes cannot exceed truck capacity. Finally, the constraint in equation (6) provides the binary variable to indicate whether the truck travels from location i to location j. Notably, for the second stage, n refers to number of locations (1-community, 2, …, n-markets), while P_i is the demand from market i.

Proposed heuristic algorithms

Two heuristic algorithms were used to search for the optimal route: 1) the K-mean method; and 2) CVRP, as detailed below.

Algorithm 1
Apply K-mean to cluster cherry tomato farms into group
If pickup amount$_i$ > a truck capacity
N = Roundup (pickup amount$_i$ / truck capacity)
Remaining$_1$ = Actual pickup amount – truck capacity
For i = 1 To N
Adjusted pickup amount$_i$ = Min (truck capacity, Remaining$_i$)
Remaining$_i$ = Remaining$_{i-1}$ – truck capacity
Delete farm that pickup amount$_i$ = 0
Apply CVRP to find the route
End For
Else
Apply CVRP
End If

Algorithm 1 starts by applying K-mean to cluster the farms that are located in the same region. Then, the pickup amount is compared with the truck capacity. If the pickup amount of farm i is greater than the truck capacity, calculate the number of rounds that needs to be executed. Then, the remaining amount of cherry tomatoes that needs to be picked up is calculated by subtracting the actual pickup amount from the truck capacity. Then, the pickup amount is set to truck capacity if the truck capacity is less than the pickup amount; otherwise; it is set to the remaining pickup amount. The remaining amount is determined based on subtracting the truck capacity. Any farm without any remaining cherry tomatoes to pick up is deleted. Then CVRP is applied to find the optimal route. The algorithm repeats until it reaches the number of rounds that needs to be calculated. However, if the pickup amount is not greater than the truck capacity, CVRP is applied immediately to solve the problem.

Algorithm 2

```
Apply K-mean to cluster cherry tomato farms into group
If number of farm in group_i > number of trucks
Set number of farms in group_i = Min (number of farms,
number of trucks) by applying K-mean
 Algorithm 1 line 2 to line 13
Else
Apply Algorithm 1 line 2 to line 13
End If
```

The steps of the second algorithm are as follows. This algorithm differs from Algorithm 1 in terms of the number of rounds of the K-mean method that are executed. First, the K-mean method is applied to cluster the cherry tomato farm into groups. Then, if the number of farms in group i is greater than the number of trucks, set the number of farms in group i to the minimum between the number of farms and the number of trucks by applying the K-mean method. Then, Algorithm 1 is implemented. On the other hand, if the number of farms in group i is not greater than the number of trucks, Algorithm 1 is implemented immediately.

Results and Discussion

In case 1, the actual data was used that had been collected from the Mae Chui community enterprise. For cases 2 and 3, the amount of cherry tomatoes from the farm was increased 20% and 40%, respectively, due to planting in the winter season and using IoT, respectively. For cases 4 and 5, the number of trucks was increased using 2-wheeled and four-wheeled trucks in accordance with the policy to expand community enterprise business. For cases 6 and 7, the distance from the community enterprise depot to the cherry tomato farm was increased to 80 km and 90 km, respectively. For cases 6 and 7, the number of tomato farm was increased to 20 and 25 locations, respectively.

Clustering

The result from applying the K-mean method using the Weka software are shown in Table 3 presenting seven scenarios. Each scenario tries to find the number of groups resulting in the minimum sum square error (SSE).

Due to the same locations used in cases 1–5, the minimal SSE was the same, namely at least six clusters. Even though the SSE of five cluster did not provide the minimum SSE, a group of 5 was suggested as the increase in the SSE from 5 clusters to 6 clusters was only 0.2984%. When the location of the farms was plotted on a map, the members of each group were located in the same area. This was applied for the other cases as well. Therefore, case 6 selected the group of 13 because the SSE was the minimum (0.1142). For case 7, the group of 13 was also selected due to the minimum SSE being 0.0230. The results are demonstrated in Table 3.

Table 3 SSE for each number of clusters

Scenario	Number of clusters						
	2	3	4	5	6	…	13
Case 1	0.7720	0.3803	0.3121	0.2681	0.2673	…	0.2673
Case 2	0.7720	0.3803	0.3121	0.2681	0.2673	…	0.2673
Case 3	0.7720	0.3803	0.3121	0.2681	0.2673	…	0.2673
Case 4	0.7720	0.3803	0.3121	0.2681	0.2673	…	0.2673
Case 5	0.7720	0.3803	0.3121	0.2681	0.2673	…	0.2673
Case 6	1.7146	0.9267	0.7457	0.5193	0.3466	…	0.1142
Case 7	0.8395	0.7163	0.3912	0.3735	0.3557	…	0.0230

Routing

Since the demand for cherry tomatoes did not change, this study omitted the transportation stage from the Mae Chui community enterprise depot to the markets. Table 4 presents the total distances and percentage reduction in the first stage CVRP (from the cherry tomato farm to the Mae Chui community enterprise depot under current practise compared to the two proposed methods.

Based on the results in Table 4, the total distance in the first stage of the real case study (case 1) was 15,986.8 km. When the amount of cherry tomatoes from the farm increased 20% and 40% (case 2 and case 3, respectively), the distance increased to 1.67 and 2.86 times, respectively, compared to the real case study. However, when two-wheeled and four-wheeled trucks (case 4 and case 5, respectively), the total distance did not change because the distances from all trucks were combined. For cases 6 and 7, when the distance from the community enterprise depot to the cherry tomato farm increased to 80 km and 90 km, respectively, the total distance increased 1.03 and 1.08 times, respectively compared to the real case study because the number of tomato farms had increased to 20 and 25, respectively.

As indicated in Table 4 there is a small reduction provided by applying Algorithm 1 and Algorithm 2 compared to AS-IS process of 0.44–2.42 percent based on all cases. This was due to all of the calculation rounds in lines 5–10 of Algorithm 1 and Algorithm 2 involved the trucks carrying their full capacity of cherry tomatoes from the farm. There was only one remaining round that the truck could pick up cherries from many farms as presented in the example case in the practical implication section. Furthermore, the results indicate there was no substantial difference between Algorithm 1 and Algorithm 2 because the two algorithms used the same rout

Based on the fuel consumption rate of 14.79 km/L and the average diesel fuel price of THB 31.85/L, the fuel consumption cost was THB 2.15/km. The total fuel costs for the first stage of the CVRP algorithm are presented in Table 5. The pattern of the total fuel cost for the current AS-IS process and two proposed methods increased from case 1 to case 7 is the same as for the total distance presented in Table 4. Furthermore, the percentage reductions in total fuel costs from applying the proposed algorithms compared with the AS-IS process followed a similar with the percentage reduction in the total distance.

Table 4 Total distances in first stage of CVRP algorithms

Scenario	AS-IS (current)	Heuristics method		%Reduction	
		Algorithm 1	Algorithm 2	Algorithm 1	Algorithm 2
Case 1	15,986.80	15,856.80	15,856.80	0.81	0.81
Case 2	26,697.96	26,547.96	26,547.96	0.56	0.56
Case 3	45,722.25	45,522.25	45,522.25	0.44	0.44
Case 4	15,986.80	15,856.80	15,856.80	0.81	0.81
Case 5	15,986.80	15,856.80	15,856.80	0.81	0.81
Case 6	16,496.80	16,146.80	16,146.80	2.12	2.12
Case 7	17,346.80	16,926.80	16,926.80	2.42	2.42

Table 5 Total fuel costs for first stage of CVRP algorithms

Scenario	AS-IS (current)	Heuristics method		%Reduction	
		Algorithm 1	Algorithm 2	Algorithm 1	Algorithm 2
Case 1	34,427.29	34,092.12	34,092.12	0.97	0.97
Case 2	57,493.58	57,078.11	57,078.11	0.72	0.72
Case 3	98,462.05	97,872.84	97,872.84	0.60	0.60
Case 4	34,427.29	34,092.12	34,092.12	0.97	0.97
Case 5	34,427.29	34,092.12	34,092.12	0.97	0.97
Case 6	35,525.56	34,715.62	34,715.62	2.28	2.28
Case 7	37,356.02	36,392.62	36,392.62	2.58	2.58

Practical implications

Case 1 represents the actual conditions used by the Mae Chui community enterprise, involving the two stages of transporting the cherry tomatoes from the farms to the Mae Chui community enterprise depot and then, in the second stage, transporting the cherries to markets. Because there were many farms in the first stage while in the second stage, there were only two markets, the K-mean method was only applied to group the farms in the first stage. Based on those results, the cherry tomato farms that were categorized into five clusters, with the farm ID, latitude, longitude and pickup amount presented in Table 6.

Cluster 0 consisted of two farms (Farm 01 and Farm 02), cluster 1 contains nine farms (Farms 11–19), cluster 2 was composed of two farms (Farm 21 and Farm 22), cluster had three farms (Farm 31, Farm 32 and Farm 33) and cluster 4, was composed of only Farm 41. The geographical locations are presented in the map in Fig. 2.

Table 6 Cherry tomato farm clusters

Cluster	Farm ID	Longitude (East)	Latitude (North)	Pickup amount (kg)
0	Farm 01	100.093	14.053	2,292
0	Farm 02	100.082	14.000	35,826
1	Farm 11	100.120	14.113	13,961
1	Farm 12	100.116	14.129	2,929
1	Farm 13	100.123	14.113	3,925
1	Farm 14	100.120	14.113	50,150
1	Farm 15	100.123	14.113	16,990
1	Farm 16	100.123	14.113	1,402
1	Farm 17	100.123	14.113	9,463
1	Farm 18	100.122	14.113	8,319
1	Farm 19	100.123	14.113	11,119
2	Farm 21	99.934	14.261	17,255
2	Farm 22	100.153	13.702	12,375
3	Farm 31	100.108	14.161	7,675
3	Farm 32	100.089	14.197	1,813
3	Farm 33	100.103	14.162	1,411
4	Farm 41	100.587	13.858	7,626

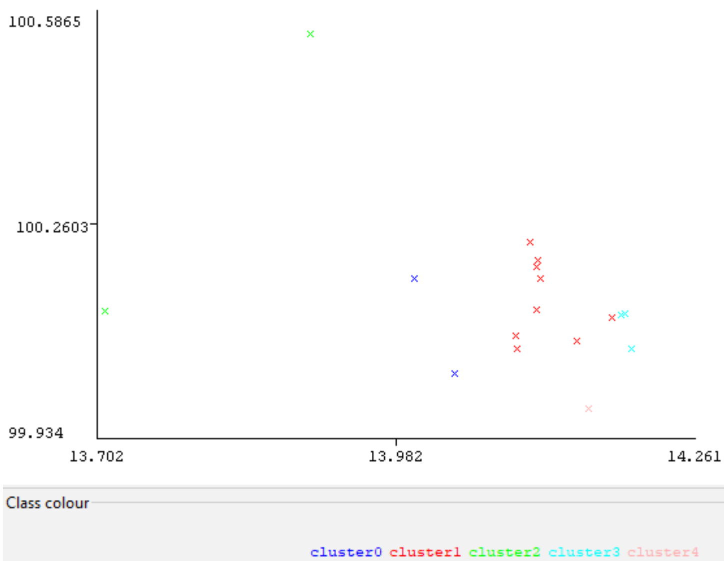

Fig. 2 Geographical representation of cherry tomato farm clusters

Cluster 2 and cluster 3 were used to illustrate practical implications. The results of applying Algorithm 1 with cluster 2 are presented in Table 7.

The actual pickup amounts of cherry tomatoes were 17,255 kg from Farm 21 and 12,375 kg from Farm 22. The capacity of the trucks was 3,000 kg, with three trucks available. Therefore, two trucks travelled to pick up the cherry tomatoes from Farm 21 using two round trips at full capacity per trip. Another truck went to pick up the cherry tomatoes from Farm 22 using four round trips at full capacity. Thus, the remaining amounts at Farm 21 and Farm 22 were 2,255 kg and 375 kg, respectively, as presented in Table 7. To minimize the total distance, the final route of an empty truck was from the community enterprise depot to Farm 22 to pick up the remaining 375 kg of cherry tomatoes and then to Farm 21 to pick up the remaining 2,255 kg, before returning to the community enterprise depot with a load of 2,630 kg. This route is shown in Table 7 and illustrated in Fig. 3.

Table 7 Amounts of cherry tomatoes transported from farms to Mae Chui community enterprise depot in final round

Route	Mae Chui	Farm 21	Farm 22	Remaining amount (kg)
To Mae Chui	0	2,630	0	
From Farm 21	0	0	375	2,255
From Farm 22	0	0	0	375

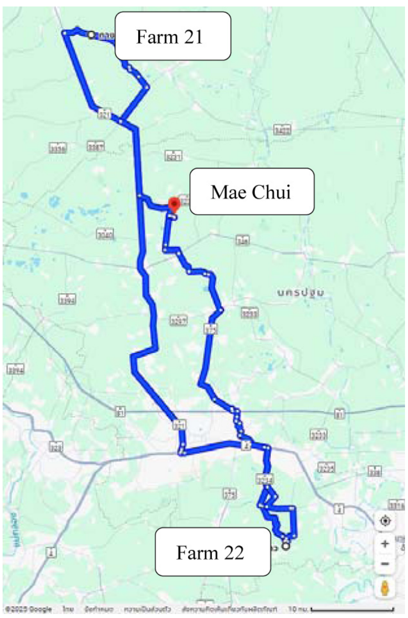

Fig. 3 Route of cluster 2 from cherry tomato farms to Mae Chui community enterprise depot

The results from applying proposed Algorithm 1 to cluster 3 are shown in Table 8.

Table 8 Amounts of cherry tomatoes transported from farms to Mae Chui community enterprise depot in first round

Route	Mae Chui	Farm 31	Farm 32	Farm 33	Pickup amount (kg)
From Mae Chui	0	3,000	1,813	1,411	
To Farm 31	0	0	0	0	7,675
To Farm 32	0	0	0	0	1,813
To Farm 33	0	0	0	0	1,411

The pick up amounts from Farm 31, Farm 32 and Farm 33 were 7,675 kg, 1,813 kg and 1,411 kg, respectively. To determine the route to pick up all these amounts, the process was divided into two rounds. In the first round, three trucks were used simultaneously, with each truck collecting cherry tomatoes from different farms. Thus, Truck 1 transported 3,000 kg of cherry tomatoes from Farm 31, truck 2 transported 1,813 kg of cherry tomatoes from Farm 32 and truck 3 transported 1,411 kg of cherry tomatoes from Farm 33. The route is presented in Fig. 4.

The remaining cherry tomatoes requiring transport were 4,675 kg of tomatoes from Farm 31 and none from Farm 32 and Farm 33. Thus, two trucks were used simultaneously to transport the 4,675 kg from Farm 31 to the Mae Chui community enterprise depot. In this second round, the first truck carried 3,000 kg, leaving 1,675 kg for the second truck.

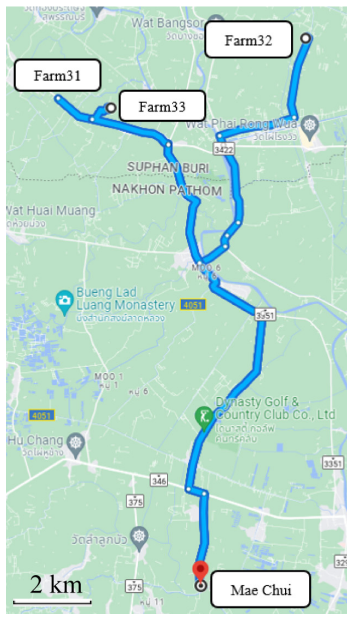

Fig. 4 Route from cherry tomato farms to Mae Chui community enterprise depot in first round

In the second stage, the cherry tomatoes were transported from the Mae Chui community enterprise depot to the markets. The results from applying proposed Algorithm 1 are presented in Table 9.

Table 9 Amounts of cherry tomatoes transported from Mae Chui community enterprise depot to markets

Route	Mae Chui	Market 1	Market 2	Delivery amount (kgs)
From Mae Chui	0	2,560	0	
To Market 1	0	0	1,000	1,560
To Market 2	0	0	0	1,000

The actual delivery amounts of cherry tomatoes from the Mae Chui community enterprise depot to Market 1 and Market 2 were 10,560 kg and 55,000 kg, respectively. The process to find the route to deliver these amounts was divided into 19 rounds. For one of the rounds, the delivery amounts from the Mae Chui community enterprise depot to Market 1 and Market 2 were 2,560 kg and 1,000 kg, respectively, while in the other rounds the trucks carried their full capacity of product directly to the destination. The route is presented in Fig. 5.

Conclusion

This research proposed a heuristic algorithm combined with MILP to solve a two-stage CVRP. The first stage involved picking up the cherry tomatoes from the farms, while the second stage delivered the tomatoes to the markets. The K-mean method was applied to cluster the cherry tomato farms into groups. For cases 1–5, there were 5 groups, while case 6 and case 7 each contained 13 groups. Based on the experimental results, the proposed heuristic algorithm produced 0.44–2.42% reductions in the total distance and 0.60–2.58% reductions in the fuel cost in the first stage of transportation. Practical implications were also considered in this study.

Since the proposed heuristic algorithms provide only a small percentage reduction in the total distance and total cost, further study is recommended to propose other heuristic methods to compare with this benchmark study. In addition, other components that could be considered in the algorithm are the waste management system, food delivery and third party logistics.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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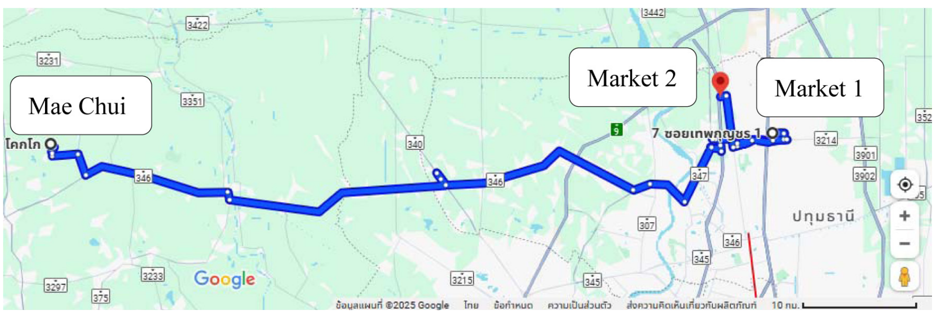

Fig. 5 Route from Mae Chui community enterprise depot to markets

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