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Heuristic Approach for Location Planning of Electric Vehicle Charging Stations on Thailand Highway Network Systems

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Abstract

Thailand is in the beginning phase of introducing electric vehicle technology. The chief barriers of introducing electric vehicles to consumers are insufficient charging stations. The provision of building enough charging stations plays an important role in the success of promoting electric vehicles. Since building a charging station is costly, the best approach is to install charging stations on optimal locations to provide adequate recharging services and minimizing total investment. In this research, the problem of selecting charging station locations, as well as minimizing the total number of charging stations, is considered. Multi-class electric vehicles with various driving ranges are included in the model. As electric vehicles have short driving ranges, the charging stations must cover the entire route. The heuristic approach of selecting charging stations, based on multi-class electric vehicles, is introduced. The proposed algorithm minimizes the number of charging stations that cover entire route. A case study of selecting charging stations on highways from Bangkok to the North-Eastern region of Thailand with 21 possible charging stations is considered. The multi-class electric vehicle has driving ranges of 120 km, 200 km, and 300 kilometers. The results showed that solutions are obtained. Fifteen locations of EV charging stations were selected to construct. These selected EV charging station locations assured that electric vehicles with all three different driving ranges will not run out of battery when traveling in the region. The results can be used to guide government-funded infrastructure.

Keywords

electric vehicles; charging station locations; infrastructure planning; heuristic approach

1. Introduction

Many countries around the world have paid attention to the importance of global warming. The study of the scientists found that the change of the average temperature of the Earth correlates with the change in carbon dioxide concentration in the atmosphere. Carbon dioxide concentration has been increasing because of fuel combustion such as oil, coal, natural gas from the process of manufacturing in the industry or the engine in transportation [1].

Nowadays, car manufacturers and consumers begin to turn their attention to alternative fuel vehicles such as biodiesel fuel vehicles, hybrid vehicles, hydrogen energy vehicles and electric vehicles. Electric vehicles (EVs) are one of the most environmental friendly vehicles as they do not emit carbon dioxide that pollutes the atmosphere, reduce global warming and noise pollution with higher energy efficiency than regular cars.

Many countries have developed policies to encourage the use of EVs such as investment in EV charging stations and promotion for purchasing EVs. Thailand is in the beginning phase of promoting EV technology for consumers. Most of the EVs in Thailand are hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEV), while the battery electric vehicles (BEV) are not yet commercialized. The major barriers of introducing EVs are that the charging stations are scarce, battery capacity is still limited, long battery charging time, and limited driving range. Among those factors, limited accessibility to charging facilities has been emphasized as a crucial problem that largely constrains market acceptance of EVs. Thus, EV users who want to make a round trip from origin to destination, must consider whether their EVs have charging stations along the way. The Thai ministry of energy has planned to promote the usage of EVs in Thailand. The provision of enough EV charging stations plays an important role in the success of promoting EVs. The best approach to solve EV limitation is to install charging stations on optimal locations to provide recharging services. The cost of building a charging station is considered expensive. Therefore, Thai government must be careful on planning for charging station locations to provide good services and minimize infrastructure costs. If charging station locations are adequate and convenient for users, the success of promoting EV is guaranteed [2].

Owen and Daskin [3] reported on literature which explicitly addressed the strategic nature of facility location problems by considering either stochastic or dynamic problem characteristics. There are several models and solutions to this problem such as median, covering, and center problems. In median problems, the objective function is to minimize the total demand-weighted distance between customers and facilities. The objective function of covering problems is to minimizes the cost of facility location or to maximize the amount of demand covered. In center problems, the objective function is simply to minimize the maximum distance between any demand node and its nearest facility. Dynamic deterministic problems have the same objective function as covering problems but their solutions may be an optimal values or just close to the optimal values. Scenario planning models with the objective function are to minimize the expected regret.

Many researchers have developed facility location problems to study optimal locations of alternative fuel refueling stations. There are many factors to consider locating alternative fuel refueling stations. Some researchers are interested in the factor of driving pattern. For example, [4] developed and applied a model that locates hydrogen stations to refuel the maximum volume of vehicle flows in Florida by inputs to the model include a road network with average speeds, the origin–destination flow volumes between each origin and destination, a maximum driving range between refueling stops, and the number of stations to build. Capar and Kuby [5] proposed an efficient formulation of the flow refueling location model since their model does not need the pre-generation stage of feasible refueling station combinations by using several networks of different sizes. It was shown that the proposed model solves the flow refueling location model to optimality as fast as or faster than currently utilized greedy and genetic heuristic algorithms, [6] reformulated the flow refueling location model , which was able to obtain an optimal solutions much faster than the previous set covering version and the model also could be solved in the maximum covering form in a reasonable time on the large-sized networks. Andrews et al. [7] studied how the EVs of today would perform in meeting the driving needs of vehicle owners and proposed the modeling and optimization for EV charging infrastructure. Chen et al. [8] studied the EV charging station location problem in a parking-based assignment method for Seattle. Kim et al. [9] developed the deviation version of the flow refueling location model with the objective of maximizing the total traffic flow covered by the stations on deviation paths. Ventura et al. [10] proposed the continuous version of the refueling station location problem on a tree network, so as to locate a single alternative-fuel refueling station to maximize the traffic flow covered in round trips per day. Asamer et al. [11] developed model for optimizing charging station locations for urban taxi providers. Hof et al. [12] studied the battery swap station location-routing problem with capacitated EVs using an AVNS algorithm for vehicle routing problems with intermediate stops. Wang et al. [13] developed model for plug-in EV travel patterns and charging load based on trip chain generation study.

Upchurch et al. [14] considered refueling pattern by introducing capacitated flow refueling location models that limits the number of vehicles refueled at each station and [15] considered the spatial refueling patterns of alternative-fuel and gasoline vehicle drivers in Los Angeles.

Micari et al. [16] developed a model that considered EV charging infrastructure planning in a road network by using the demand (the flow of EVs) and the supply (the road network where they will be positioned) through a two-level model. Locations were initially identified (first level) and thereafter the number of charging stations for each service area (second level) evaluated.

Some researchers are interested in demand dynamics with multi-period model such as [17] who studied Multi-period planning for EV charging station locations in a case of Korean Expressways. Miralinaghi et al. [18] considered the capacitated refueling station location problem with traffic deviations over multiple time periods. Zhang et al. [19] developed a model that incorporating demand dynamics in multi-period capacitated fast-charging location planning for EVs.

The factors of routing choices and demand uncertainty have been studied by [20] who analyzed capacity and designed network with degradable links. They characterized this route choice behavior in uncertain travel times with the notion of probabilistic user equilibrium (PUE). Kim and Kuby [21] studied the deviation-flow refueling location model for optimizing a network of refueling stations. Capar et al. [22] developed an arc cover–path-cover formulation and strategic analysis of alternative-fuel station locations. He et al. [23] considered the optimal deployment of public charging stations for plug-in hybrid EVs with captures the interactions among availability of public charging opportunities, prices of electricity, and destination and route choices. Yıldız et al. [24] developed a branch and price approach for routing and refueling station location model. Miralinaghi et al. [25] studied the refueling station location problem with traffic deviation considering route choice and demand uncertainty.

Huang et al. [26] proposed two optimization models for two different charging modes (fast and slow charging) in EV charging network and [27] were also interested in the factor of fast and slow charging stations by study the data-driven approach to operation and location considering range anxiety of one-way EVs sharing system.

Vehicle driving range is another factor that has been extensively studied. The problem is divided into two categories, single vehicle driving range and multiple vehicle driving ranges. Single vehicle driving range is considered an EV with a fixed driving range in the model. This problem has been studied by [14] and [5]. Lee et al. [28] identified locations for charging stations by using a probabilistic distribution function for the remaining fuel range. Their location model was developed based on user equilibrium assignment. They also considered the congested traffic conditions of urban areas in order to avoid locating charging stations where they could cause further traffic congestion. Kang et al. [29] proposed an integrated decision-making framework to assess profitability of a cooperative business model using a multidisciplinary optimization model that combines marketing, engineering, and operations considerations. The model demonstrated in a case study including battery EV design and direct current fast charging stations location network in Southeast Michigan.

Multiple-class vehicle with various driving ranges have been extensive studied by [30] who considered the flow-refueling location problem for alternative-fuel vehicles by considering the limited range of vehicles. Kuby et al. [31] introduced and compared three methods for generating additional discrete candidate sites along the arcs of a network for obtaining better solutions to the flow refueling location model with the same number of facilities. Wang and Lin [32] extended the set-covering problem for proposing a refueling-station-location model using a mixed integer programming method, based on vehicle-routing logics. The model evaluates whether a vehicle at a given site can arrive to the next site with the fuel remaining in the tank and sensitivity analysis shows that greater vehicle range will result in a lower number of refueling stations that need to be sited. Lim and Kuby [33] presented three heuristic algorithms that solve for the flow refueling location model for locating refueling stations to maximize the flow that can be refueled with a given number of facilities by uses path-based demands. Because of the limitations imposed by the driving range of vehicles, longer paths require combinations of more than one station to refuel round-trip travel. Hwang et al. [34] proposed a new mathematical model for developing AF infrastructures on directed (symmetric) transportation networks when vehicles traveling the network have the same driving range and similar fuel levels at the origin-destinations, [35] introduced a multi-class vehicle transportation network in which vehicles have different driving ranges and fuel tank levels at their origins and destinations.

In this research, the problem of selecting EV charging station location is considered, assuming that the number of EVs in Thailand will increase in the near future and there is no EV charging stations at present. Multi-class vehicles with various driving ranges are included in the model. As EVs have short driving ranges, the charging stations must cover the entire route. The problem of selecting EV charging station on highways from Bangkok to the North-Eastern part of Thailand is considered. Unlike [30], [31], [32], [33], and [34], the heuristic approach in this research is not based on flow refueling location model. The heuristic approach of selecting EV charging stations has developed, based on algorithm that first determine the minimum number of charging stations required and then determine the locations of EV charging stations. The proposed algorithm aims to minimize the number of EV charging stations that cover entire route by determining the locations of EV charging stations, when traveling from one location to destination location with various EV driving ranges. The results can be used to guide government-funded infrastructure in order to grow EV infrastructure and industries in Thailand while minimizing construction budget. This model is suitable for preliminary phase of implementing EV systems.

The paper is organized as follows. A problem description is presented in section two. In section three, the solution methodology is introduced. The numerical examples and results are shown in section four. In section five, the conclusion of this research is described.

2. Problem description

In this paper, the case study of five major highways (Highway number 1, 2, 22, 23, and 24) from Bangkok to North-Eastern Thailand are considered. There are 21 districts with high population across the highways that have been selected to be possible sites to locate EV charging stations. The main purpose of this research is to determine where the EV charging stations should be located as well as minimize the total number of EV charging stations, when driving round trip from origin node (i) to destination node (j). d_{ij} is a distance between node i and node j. A driving range of EV is called R_i. As EVs have a limited driving range that can run on one charge, multi-class of electric vehicles are considered with different driving ranges. This research is assumed that there is no other charging station available on highways at present. The appropriate locations of EV charging stations for investment are intended to cover all EV driving ranges.

3. Solution methodology

The heuristic approach determining the locations of EV charging stations, as well as minimizing the total number of EV charging stations, is described below:

Step 1: Determine the shortest path of all network combinations using mathematical formulation developed by [36].

Input notation:

S = source node

T = target node

Decision variables:

$$X_{ij} = \begin{cases} 1 & \text{if an arc is on the shortest path,} \\ 0 & \text{otherwise.} \end{cases}$$

The mathematical model is derived as follows:

$$\min Z = \sum X_{ij} d_{ij} \quad (1)$$

Subject to:

$$\sum_j X_{ij} - \sum_j X_{ji} = \begin{cases} 1, & \text{if } i = S; \\ -1, & \text{if } i = T; \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

The objective function (1) is to minimize the total distance of all arcs on in the shortest path. Constraint (2) determines the net flow (flow out - flow in) of each node. Node S should only have one outgoing arc (net flow = 1). Node T should only have one ingoing arc (net flow = -1). All other nodes should have one outgoing arc and one ingoing arc if the node is on the shortest path (net flow = 0) or no flow. For each pair of node i and node j, the shortest path obtaining from mathematical model above is saved in array $route(i, j)$.

Step 2: Find the minimum number of EV charging stations to be constructed (n) in each route. Given that the battery is fully charged at the origin node (i) and travel to destination node (j). Based on array $route(i, j)$ in step 1, find the cumulative distance of the route starting from origin node i. When the cumulative distance is exceeded the EV driving range, the previous point will be the location to construct an EV charging station. Then find the next charging station where cumulative distance exceeds EV driving range from the previous point. Repeat this step until reaching the destination node (j). Save all the chosen points as EV charging stations in array $choosed(i, j)$ and the number of EV charging stations required to complete the trip in the array is saved as n. Go to step 3.

Step 3: Find alternative locations of EV charging stations in each route. The minimum number of EV charging stations (n) found in step 2 is used to determine alternative locations of EV charging stations in each route. The alternative EV charging locations from node i to node j, which use the same number of EV charging stations, can be determined as follows:

Set q = 1. Starting from origin node i.

3.1) Find possible charging locations where EV can reach without exceeding EV driving range and save those locations as the possible EV charging stations.

3.2) From locations selected in step 3.1, set those possible charging locations as starting points, set $q = q+1$, and go to step 3.1.

3.3) Repeat steps 3.1 and 3.2 until a value of q reaching $n+1$.

3.4) Save all routes that can reach the destination node (j) in array $allcslocation$ (i,j). These locations are considered to be alternative possible EV charging stations. Eliminate routes that cannot reach destination node (j). Those routes cannot be alternative possible EV charging stations.

Step 4: Repeat Steps 2 and Step 3 for all origins and destinations (i,j) of each EV driving range (R_i).

Step 5: Calculate the total frequency of each EV charging station location in all possible routes. For all possible routes in array $allcslocation(i,j)$ obtained from step 4, determine the total frequency of EV charging station locations that has been chosen. Thus, each EV charging station location are attached with its frequency that it is chosen in all possible routes. EV charging station with higher frequency is more likely to be selected to construct.

Step 6: For all possible routes from origin node (i) to destination node (j), calculate the total frequency of all EV charging stations in each route. The total frequency is used to determine the best route in the next step.

Step 7: For all possible routes from origin node (i) to destination node (j), choose one route in each driving range that has the highest total frequency. This route is considered to be the best route among other possible routes. All EV charging stations in this route are chosen to be constructed. Eliminate all other possible routes.

Repeat steps 6 and 7 for all values of i and j.

All of the chosen locations obtained from step 7 for all values of i and j in all driving ranges are considered to be the sites to construct EV charging stations.

4. Numerical examples

In this paper, five highways in the North-Eastern of Thailand, highway number 1, 2, 22, 23, and 24, are considered. There are 21 districts across the region that have been selected to be possible locations to

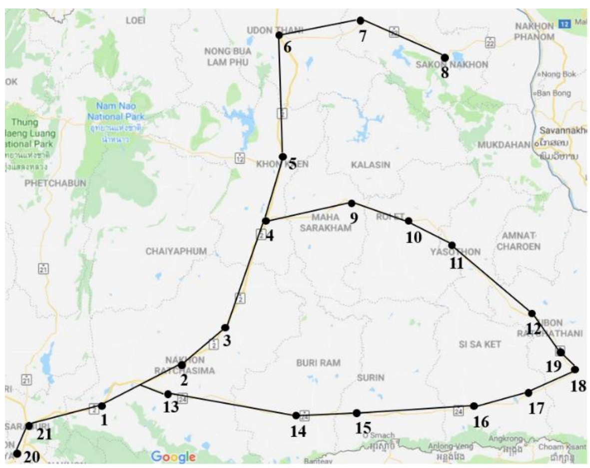

Fig. 1 The map showing five highways and 21 possible locations to construct EV charging stations.

Table 1 The distance (d_{ij}) from the origin point (i) to destination point (j).

i	j	d_{ij} (km)	i	j	d_{ij} (km)	i	j	d_{ij} (km)
1	2	87.5	7	6	77.1	14	15	38.3
1	13	81.5	7	8	78	15	14	38.3
1	21	60.5	8	7	78	15	16	86.9
2	1	87.5	9	4	74.9	16	15	86.9
2	3	52.3	9	10	38.1	16	17	50
2	13	81.3	10	9	38.1	17	16	50
3	2	52.3	10	11	62.4	17	18	48.9
3	4	94.9	11	10	62.4	18	17	48.9
4	3	94.9	11	12	104	18	19	28.1
4	5	46.8	12	11	104	19	18	28.1
4	9	74.9	12	19	17.4	19	12	17.4
5	4	46.8	13	1	81.5	20	21	53.6
5	6	117	13	2	81.3	21	1	60.5
6	5	117	13	14	116	21	20	53.6
6	7	77.1	14	13	116			

Table 2 The partial result of the shortest path in array $route(i,j)$.

i	j	$route(i,j)$									$dist(i,j)$
1	2	1	2								87.5
1	3	1	2	3							139.8
1	4	1	2	3	4						234.7
1	5	1	2	3	4	5					281.5
…	…	…									…
4	12	4	9	10	11	12					279.4
…	…	…									…
20	21	20	21								53.6

construct EV charging stations. Possible locations are selected by scrutinizing districts that have more than 100,000 inhabitants on highway number 1, 2, 22, 23, and 24 as depicted in Figure 1. Three EV driving ranges are considered, R_1 = 120, R_2 = 200, and R_3 = 300 km, assuming that there is no other EV charging station available at present. The distance (d_{ij}) from origin node (i) to destination node (j) is obtained from actual distance from Google Map as described in Table 1. MATLAB is used to develop heuristic approach and find locations for EV charging stations.

Step 1: Determine the shortest path of all combinations (i, j) in the network. The shortest path ($route(i,j)$) and distance ($dist(i,j)$) are shown in Table 2. The origin node 4 and the destination node 12 (i = 4, j = 12) is selected to demonstrate our heuristic algorithms throughout this section. The shortest route from location 4 to location 12 is depicted in Figure 2. The shortest path of this route, $route(4,12)$, is {4,9,10,11,12} and $dist(4,12)$ is 279.4 km. Due to a number of results, only partial results can be shown here. Full results of Table 2 can be found here: Completed Table 2

Step 2: Find the minimum number of EV charging stations (n) to be selected and save all the chosen locations as EV charging station in array $choosed(i,j)$ as shown in Table 3. Only partial results can be shown in the table. The full results can be found here:

Fig. 2 The example of the shortest path between point 4 (origin, i = 4) and point 12 (destination, j = 12).

Table 3 The partial results of selected locations of EV charging station.

i	j	R_i	n	$choosed(i,j)$		
1	2	120	0			
		200	0			
		300	0			
1	3	120	1	2		
		200	0			
		300	0			
1	4	120	2	2	3	
		200	1	3		
		300	0			
1	5	120	3	2	3	4
		200	1	3		
		300	0			
...	...	...	...			
4	12	120	2	10	11	
		200	1	11		
		300	0			
...	...	...	...			
20	21	120	0			
		200	0			
		300	0			

Completed Table 3. Traveling from location 4 to location 12, the cumulative distance from location 4 has exceeded the EV driving range of 120 km at location 11, so the location of EV charging station is located at point 10. The next cumulative distance from location 10 that has exceeded the EV range is at location 12, thus, the second location of EV charging station on this route is at location 11. Then, from location 11 electric vehicles can reach the destination or location 12 without requiring another charging station. Therefore, in case of 120 km EV range two EV charging stations are needed (n = 2) to travel from location 4 to location 10. In case of EV driving range equal to 200 km, the cumulative distance from location 4 has exceeded the EV driving range at location 12, so the first location of EV charging station is at location 11. From location 11 electric vehicles can reach the destination or location 12 without charging station. Therefore, only one EV charging station are needed (n = 1) in case of 200 km driving range. In case of 300 km driving range, distance from location 4 to location 12 is not exceed EV driving range, thus, no EV charging station is required in this case (n = 0).

Step 3: Find other possible locations of EV charging stations. All alternative possible routes are saved in array $allcslocation(i,j)$. We consider our example when traveling from location 4 to location 12 and EV driving range is 120 km with n = 2. In round 1 (q = 1), EVs travel from location 4 can reach location 9 and location 10. In round 2 (q = 2), possible locations from point 9 are locations 10 and 11, and possible locations of point 10 are point 11. In final round (q = 3), only location 11 can reach the destination or location 12 without EV battery running out. Therefore, there are 2 other possible routes to locate EV charging stations from location 4 to location 12. We can locate EV charging stations at location 9 and location 11 or location 10 and location 11. Array $allcslocation(4,12)$ stores value as $\begin{Bmatrix} 9 & 11 \\ 10 & 11 \end{Bmatrix}$ .The origin and destination points are not stored in array

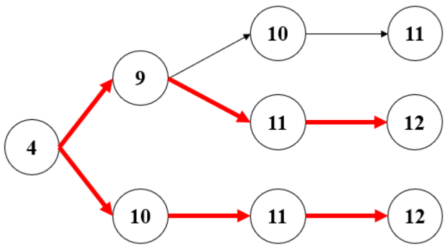

Fig. 3 Alternative routes from i = 4 to j = 12 when driving range is 120 km.

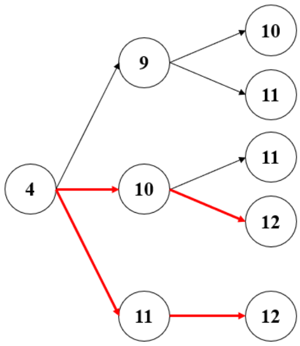

Fig. 4 Alternative routes from i = 4 to j = 12 when driving range is 200 km.

$allcslocation(i,j)$. In other words, there are other two possible routes 4-9-11-12 and 4-10-11-12 as shown in Figure 3. When EV driving range is 200 km with n =1 and q =1, Evs travel from location 4 can reach locations 9, 11, and 12. When q =2, the possible charging station locations of location 10 are locations 11 and 12, and other possible charging station of location 11 is location 12. Only locations 10 and 11 can reach a destination without battery running out. Thus, there are 2 ways to locate EV charging stations by constructing EV charging stations at locations 10 or 11. Array $allcslocation(4,12)$ stores value of $\begin{Bmatrix}10\\11\end{Bmatrix}$. In other words, there are other two

Table 4 The partial results of all alternative locations of EV charging stations with EV driving ranges of 120 km, 200 km, and 300 km.

i	j	R_i	n	$choosed(i,j)$		
1	2	120	0			
		200	0			
		300	0			
1	3	120	1	2		
		200	0			
		300	0			
1	4	120	2	2	3	
		200	1	3		
		300	0			
1	5	120	3	2	3	4
		200	1	3		
		300	0			
...	...	...	...			
4	12	120	2	10	11	
		200	1	11		
		300	0			
...	...	...	...			
20	21	120	0			
		200	0			
		300	0			

possible routes 4-10-12 and 4-11-12 as shown in Figure 4.

When EV driving range is 300 km with n =0 and q =1, distance from location 4 to location 12 is not exceed EV driving range. Thus, EV charging station is not required in this case.

Step 4: Repeat Step 2 and Step 3 for all combinations of each EV driving range, 120 km, 200 km and 300 km. All alternative possible ways are

Table 5 The frequency of each selected location of the EV charging station.

Locations	Frequency	Locations	Frequency
1	97	12	123
2	163	13	142
3	157	14	129
4	299	15	105
5	233	16	86
6	136	17	86
7	52	18	59
8	0	19	42
9	101	20	0
10	137	21	21
11	177		

saved in array $allcslocation(i, j)$ as shown in Table 4. Only partial results can be shown in Table 4. Full results can be found here: Completed Table 4.

Step 5: Calculate the total frequency of each EV charging station location in all possible routes, $allcslocation(i, j)$, obtained from step 4. The frequency of each selected EV charging station location from the results in Table 4 are shown in Table 5.

Step 6: For all possible routes from origin (i) to destination point (j), calculate the total frequency of all selected EV charging stations in each route as shown in the last column of Table 4. Consider our case study of traveling from i = 4 to j = 12 with driving range of 120 km. There are two possible routes which are 4-9-11-12 and 4-10-11-12. In Table 5, the frequency of points 9, 10, and 11 are 101, 137, and 177, respectively. In route 4-9-11-12, there are two EV charging stations at location 9 and 11. The total

Table 6 The partial results of EV charging station locations in each route with EV driving ranges of 120 km, 200 km, and 300 km.

i	j	R_i	n	EV charging stations locations			Frequency
1	2	120	0	-			0
		200	0	-			0
		300	0	-			0
1	3	120	1	2			163
		200	0	-			0
		300	0	-			0
1	4	120	2	2	3		320
		200	1	2			163
		300	0	-			0
1	5	120	3	2	3	4	619
		200	1	2			163
		300	0	-			0
...	...	...	...	...			...
4	12	120	2	10	11		314
		200	1	11			177
		300	0	-			0
...	...	...	...	...			...
20	21	120	0	-			0
		200	0	-			0
		300	0	-			0

frequency in this route is 278. In route 4-10-11-12, there are two EV charging stations at location 10 and 11. The total frequency in this route is 314 as shown in the last column of Table 4.

Step 7: For all possible routes from origin node (i) to destination node (j), choose one route that has the highest total frequency for each driving range. This route is considered to be the best route among other possible routes. Consider our case study traveling

Table 7 Total frequency of each selected location of EV charging station after choosing the best route in each case.

Locations	Frequency	Locations	Frequency
1	45	12	53
2	110	13	84
3	60	14	77
4	190	15	38
5	85	16	44
6	54	17	44
7	20	18	0
8	0	19	0
9	0	20	0
10	49	21	0
11	93		

from i = 4 to j = 12 with driving range of 120 km in Table 4. There are two possible routes, 4-9-11-12 and 4-10-11-12, with the total frequency of 278 and 314, respectively. We choose one route that has the highest frequency, which is route 4-10-11-12. The partial results of EV charging station locations with the highest total frequency in each route are shown in Table 6. Full results can be found here: Completed Table 6.

Therefore, a pair of i and j for each driving range will return one best route that has the highest frequency. All locations in the chosen route are considered to be the sites to construct EV charging stations. Finally, determine all chosen EV charging station locations for each pair of i and j for all driving ranges from results in Table 6. The total frequency of each location obtained after choosing the best route from Table 6 for all values of i and j

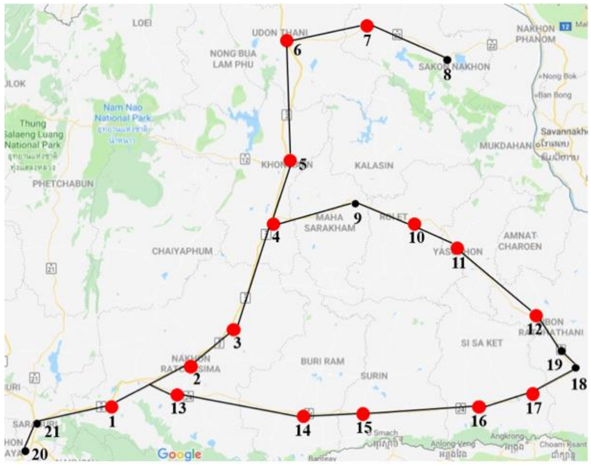

Fig. 5 Display EV charging station locations

is shown in table 7. The locations with higher frequency will have higher chance of EVs passing through and stopping for charging batteries.

Thus, the EV charging stations will be constructed in locations 1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 16, and 17, as shown in Table 7. EV charging stations are not needed in locations 8, 9, 18, 19, 20, and 21, which have zero frequency. These results guarantee that EV with all three different driving ranges will never run out of battery when traveling from any starting location to any destination as shown in Figure 5 with red dots.

5. Conclusions

Electric vehicles will become available to everyone in the near future. Planning for the infrastructure of EV is a crucial decision to make. In this research, the objective was to find the minimum number of EV charging stations to be constructed and their locations with multiple EV driving ranges assuming that there is no other EV charging stations available at present. This paper demonstrated the developed heuristic algorithms in MATLAB to find solutions in a case study of 21 possible charging station locations on 5 highways in the North-Eastern of Thailand with multiple EV driving ranges of 120 km, 200 km, and 300 km. The results showed that solutions are obtained. Fifteen locations of EV charging stations were selected to construct. These selected EV charging station locations assured that EV with all three different driving ranges will not run out of battery when traveling from any starting location to any destination in the region.

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