A Problem-based Heuristic for Asymmetric Travelling Salesman Problems

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Abstract—This paper proposes a problem-based heuristic performing well for solving asymmetric travelling salesman problem (ATSP), one of a well-known NP-hard problem. The basic concept of the proposed heuristic is to construct a round-trip route by moving from the current city to one of its adjacent cities systematically using a well selection procedure in its move's direction. Based on its simple concept, this heuristic is thus very simple and can be calculated both by hand and by PC in a short time period. The experimental results show that the proposed heuristic outperforms the nearest neighbour algorithm.

Index Terms—asymmetric travelling salesman problem, ATSP, problem-based heuristic, algorithm

I. Introduction

The traditional travelling salesman problem or TSP consists of one salesman and a number of cities; this problem attempts to find a route of the salesman that starts from the starting city and visits other cities exactly once and finally returns back to the starting city in order to minimize the total distance of one trip. The distance from each city to another is predefined. The problem is to find out a route of a salesman which starts his trip from a predefined city and then visits all the forward direction and that in backward direction are exactly the same. However, this paper will focus on the asymmetric travelling salesman problem or ATSP since it is a generalized form of TSP whose distances between a pair of cities in forward direction and in backward direction can be different.

ATSP is a NP-hard problem which is hard to solve to optimality; thus many heuristics has been developed to find a good-quality solution within a reasonable computational time. Among these heuristics, the nearest neighbour algorithm or NN seems to be simplest but very powerful. The policy of NN is to assign the salesman to move from his current city to the nearest unvisited city. Many papers use NN as the competitor of their proposed algorithms, e.g. [1]. However, a biggest weakness of NN is that NN does not have any plan to move back to the starting city systematically; thus, it is possible that NN will make the round-trip that the last visited city and the starting city are very far from each other.

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This paper proposes a simple heuristic that can be simply manipulated both by hand and by a personal computer within short computational times, since the heuristic is developed based on the human simple task procedure such as scrubbing a room floor of a housekeeper. When the housekeeper scrubs a room floor, she starts her task by moving from the room's door into the room wall located in the opposite side of the room's door. Later, she starts scrubbing from the most inside of the room and back to the door by switching left and right directions to so as clean the whole floor. This kind of tasks inspires the development of the heuristic proposed in this paper. The heuristic differs from NN in that it does not use distance between cities as the criterion for the salesman move; but the salesman of the presented heuristic tries to move from the current city to an adjacent city, e.g., a city that have its territory in contact with the current city. It initially moves the salesman from the starting city to the outmost city and then moves him back to the starting city systematically. The systematic move of the salesman of this heuristic is very similar to the housekeeper's move in her room scrubbing task as mentioned.

This paper has five sections including introduction section as Section I. Section II presents the literature review which paves the ideas to this research. Section III presents the details of the proposed heuristic. Section IV expresses the problem instances used in the experiment provided in this paper. The experiment and its results are presented in Section V and the conclusion is included in Section VI.

II. Literature Review

Travelling salesman problem (TSP) is very simple to understand since the aim of the problem is to make a round-trip that visits each city exactly once, and the last visited city must be the starting city of the round-trip. The shorter-distance round-trip is the better solution of the problem. However, on the contrary, the finding of the shortest-distance round-trip is so difficult and the problem is classified into the NP-hard problems in [2]. The classical TSP, sometimes called symmetric TSP, starts with one salesman and N cities. The distance from city i to city j or $d(i, j)$, equals the distance from city j to city i or $d(j, i)$, where $i = 1, 2,..., N$; $j = 1, 2,..., N$; and $i \neq j$. The salesman has to start his round-trip from a city selected from the N cities, as the starting city; he then

moves from the starting city to another city and so on. He is not allowed to visit the same city twice, excepting the starting city which has to be his final destination. His round-trip will end when he can visit all N cities and also come back to the starting city. Another variant of the classical TSP is the asymmetric TSP (ATSP) which is TSP in that $d(i, j)$ may not equal $d(j, i)$. The expressions of TSP and ATSP can be found in [3].

In the last fifty years, researchers have attempted to solve ATSP using many different algorithms which can be classified into three categories: (1) Exact methods which guarantee finding the optimal solution such as branch-and-cut method presented by [4] and branch-and-bound methods presented by [5]. (2) Problem-based heuristics which is the simple heuristics, some of them can compute by hand easily such as NN presented by [1] and insertion heuristics presented by [6]. (3) Meta-heuristics which use a higher-level procedure to find, generate or select a lower-level procedure that may return a good solution such as GA in [7], memetic algorithm in [8], VNS given by [9], tabu search algorithm given by [10], and ACO given by [11].

III. Proposed Heuristic

The inspiration to develop the heuristic presented in this paper is from the common idea for human daily works such as the room's floor cleaning process. For the floor cleaning task, we have to go from the room's door into the most inside area of the room and then clean from there and go back to the door. Thus, the concept of this heuristic seems to be common and can be easily found in everywhere; on the contrary, it seems to be a very high-performance method developed for a long time ago, way back in history. This paper aims to show that it also performs well in a NP-Hard problem like ATSP. This heuristic proposed in this paper will be hereafter called Adjacent Area Algorithm (AAA).

Before expressing the steps of AAA, it is necessary to inform that the route generated from AAA will always start from the northernmost city. Thus, in order to change the starting city, the map has to be rotated. There are four degrees used in the rotation for the map: 0 (as the original map), 90, 180 and 270 degrees. Hereafter, the meaning of degree is the degree of rotating the map in anticlockwise. Moreover, this research also uses the mirror image of map in which the east will become west and vise versa.

Based on the above given, the eight views of a map used in AAA are as follows: (1) Original image rotated by anticlockwise 0 degree, (2) Original image rotated by anticlockwise 90 degree, (3) Original image rotated by anticlockwise 180 degree, (4) Original image rotated by anticlockwise 270 degree, (5) Mirror image of the 0 degree anticlockwise-rotated original map, (6) Mirror image of the 90 degree anticlockwise-rotated original map, (7) Mirror image of the 180 degree anticlockwise-rotated original map, and (8) Mirror image of the 270 degree anticlockwise-rotated original map

For the illustrations in making the eight views of map mentioned above, Fig. 1 and Fig. 2 show the Thailand's maps rotated by 0 degrees in original image and in mirror image, respectively. Fig. 3 and Fig. 4 show the Thailand's maps rotated by 90 degree in original image and in mirror image respectively. The maps of different countries or the map of a part of Thailand can be transformed their views in these ways.

Figure 1. View of Thailand map in original image rotated by anticlockwise 0 degree.

Figure 2. View of mirror image of the 0 degree anticlockwise-rotated original Thailand map.

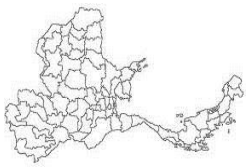

Figure 3. View of Thailand map in original image rotated by anticlockwise 90 degree.

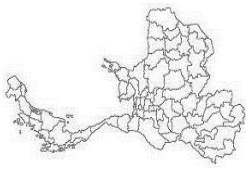

Figure 4. View of mirror image of the 90 degree anticlockwise-rotated original Thailand map.

The steps of AAA for solving ATSP are given below.

1) Select the image (Original or Mirror) and the degree (0, 90, 180 or 270) for the map used to make a round-trip.
2) For each city, assign its adjacent cities (i.e., the cities which have their territories in contact with the city being considered) into the eight directions as follows: south, southeast, east, northeast, southwest, west, northwest and north. Each of its adjacent cities must be assigned into exactly one direction; if there are two or more assignable directions for an adjacent city, select just one direction involving to the longest adjacent boundary line between the current city and this adjacent city. Moreover, one direction must have at most one adjacent city only; this means some of the eight directions may not have any adjacent city.

3) Start the travel from the northernmost city (i.e., the city situated at the farthest north of the country).
4) Travel clockwise along the adjacent border cities (i.e., the adjacent cities of the current city, which are situated on the boundary of the country) from the northernmost city to the southernmost city (i.e., the city situated at the farthest south of the country).
5) Travel from the current city to one of its adjacent cities assigned in Step 2 which has never been visited. If there are two or more unvisited adjacent cities, select the adjacent city based on the direction's priorities listed as follows: south, southeast, east, northeast, southwest, west, northwest and then north. This means the salesman will move to the adjacent city located in the south, if this city exists; if not, he will instead move to the adjacent city in the southeast and so on. In cases that the current city has no any adjacent city, then select the nearest city in distance from the current city.
6) Repeat from Step 5 until all cities have been visited; then, go back to the northernmost city.

IV. Problem Instances

The experiment in this paper attempts to compare the performances of NN and AAA. To do so, this paper generates six ATSP problem instances based on the six regions of Thailand: (1) Northern, (2) Upper central, (3) Lower central, (4) Eastern, (5) Northeast and (6) Southern & western.

Each problem instance aims to find the round-trip of all cities inside the involved region. The most famous temple in each city is assigned as the destination of each city. This paper uses Google Map to find the distances between two temples in both directions; if there is more than one path for the same destination, this paper will use the shortest path. Thus, the data about the distances can be found online in Google Map. Sections A to F show the cities belong to the northern, upper central, lower central, eastern, northeast, southern & western regions, respectively. For each city, the most famous temple is given in parentheses in back of the city's name; its adjacent cities located in the same region are also provided with the distances between the most famous temples of the city being considered and the adjacent cities. The distances from the most famous temple of the city being considered to the most famous temple of each adjacent city both in forward direction and in backward direction are given in parentheses in back of the name of the adjacent city.

A. Northern Region

The northern region includes nine cities, i.e. Lamphun, Phrae, Lampang, Mae Hong Son, Chiang Mai, Chiang Rai, Phayao, Nan and Uttaradit. Details of these cities are given below:

1) Lamphun (Wat Phra That Hariphunchai) which has its territory in contact to Lampang (70.8 km, 69.9 km) in its east, Chiang Mai (29.7 km, 29.1 km) in its north.
2) Phrae (Wat Phra That Cho Hae) which has its territory in contact to Uttaradit (77.9 km, 80.5 km) in its southeast, Nan (125 km, 125 km) in its east, Lampang (133 km, 133 km) in its west, Phayao (151 km, 152 km) in its north.
3) Lampang (Wat Phra That Lampang Luang) which has its territory in contact to Phrae (133 km, 133 km) in its east, Phayao (153 km, 154 km) in its northeast, Lamphun (69.9 km, 70.8 km)in its west, Chiang Mai (97.5 km, 101 km) in its northwest, Chiang Rai (310 km, 310 km) in its north.
4) Mae Hong Son (Wat Hua Wiang) which has its territory in contact to Chiang Mai (238 km, 235 km)in its east.
5) Chiang Mai (Wat Phra Singh) which has its territory in contact to Lamphun (29.1 km, 29.7 km) in its southeast, Lampang (101 km, 97.5 km) in its east, Chiang Rai (249 km, 254 km) in its northeast, Mae Hong Son (235 km, 238 km) in its west.
6) Chiang Rai (Wat Pratatphangao), which has its territory in contact to Lampang (310 km, 310 km) in its south, Phayao (158 km, 158 km) in its southeast, Chiang Mai (254 km, 249 km) in its northwest.
7) Phayao (Wat Srikomkham), which has its territory in contact to Phrae (152 km, 151 km) in its south, Nan (150 km, 149 km) in its east, Lampang (154 km, 153 km) in its west, Chiang Rai (158 km, 158 km) in its north.
8) Nan (Wat Suan Tan) and which has its territory in contact to Uttaradit (191 km, 194 km) in its south, Phrae (125 km, 125 km) in its west, Phayao (149 km, 150 km) in its northwest.
9) Uttaradit (Wat Tha Thanon) which has its territory in contact to Phrae (80.5 km, 77.9 km) in its northwest, Nan (194 km, 191 km) in its north.

B. Upper Central Region

The upper central region includes seven cities, i.e., Kamphaeng, Sukhothai, Pichit, Nakhon Sawan, Phethabun, Uthai Thani and Phitsanulok. Below provides their cities' details:

1) Kamphaeng Phet (Wat Thep Moree) which has its territory in contact to Nakhon Sawan (122 km, 123 km) in its south, Phichit (92.6 km, 92.7 km) in its east, Phitsanulok (99.9 km, 102 km) in its northeast, Sukhothai (88.4 km, 87.7 km) in its north.
2) Sukhothai (Wat traphangthonglang) which has its territory in contact to Phitsanulok (72.5 km, 73.5 km) in its south, Kamphaeng Phet (87.7 km, 88.4 km) in its southwest.
3) Phichit (Wat Tha Luang) which has its territory in contact to Nakhon Sawan (110 km, 111 km) in its south, Phetchabun (130 km, 130 km) in its east, Kamphaeng Phet (92.7 km, 92.6 km) in its west, Phitsanulok (58.5 km, 59 km) in its north.
4) Nakhon Sawan (Wat Nakhon Sawan) which has its territory in contact to Phetchabun (185 km, 185 km) in its east, Phichit (111 km, 110 km) in its northeast, Uthai Thani (48.6 km, 48.5 km) in its west, Kamphaeng Phet (123 km, 122 km) in its north.

5) Phetchabun (Wat Mahatath) which has its territory in contact to Nakhon Sawan (185 km, 185 km) in its southwest, Phichit (130 km, 130 km) in its west, Phitsanulok (167 km, 168 km) in its northwest.
6) Uthai Thani (Wat Sangkat Rattana Khiri) which has its territory in contact to Nakhon Sawan (48.5 km, 48.6 km) in its north.
7) Phitsanulok (Wat Phra Sri Rattana Mahathat) which has its territory in contact to Phichit (59 km, 58.5 km) in its south, Phetchabun (168 km, 167 km) in its southeast, Kamphaeng Phet (102 km, 99.9 km) in its southwest, Sukhothai (73.5 km, 72.5 km) in its west.

C. Lower Central Region

The lower central region includes fifteen cities: Saraburi, Lop Buri, Ayutthaya, Ang Thong, Sing Buri, Nonthaburi, Pathum Thani, Nakhon Pathom, Suphan Buri, Nakhon Nayok, Bangkok, Samut Prakan, Samut Sakhon, Samut Songkhram and Chai Nat. The details of these cities are given below:

1) Saraburi (Wat Phayao) which has its territory in contact to Nakhon Nayok (71 km, 72.4 km) in its south, Pathum Thani (93.6 km, 93.6 km) in its southwest, Ayutthaya (58 km, 53.7 km) in its west, Ang Thong (61.8 km, 68 km) in its northwest, Lop Buri (46.7 km, 47.5 km) in its north.
2) Lop Buri (Wat Sao Thong Thong) which has its territory in contact to Saraburi (47.5 km, 46.7 km) in its south, Ang Thong (39.7 km, 39.2 km) in its southwest, Sing Buri (38.7 km, 36.7 km) in its west.
3) Ayutthaya (Wat Phananchoeng) which has its territory in contact to Pathum Thani (51.2 km, 50.5 km) in its south, Saraburi (53.7 km, 58 km) in its east, Nonthaburi (69.2 km, 72.4 km) in its southwest, Nakhon Pathom (114 km, 117 km) in its west, Suphan Buri (68.4 km, 68.5 km) in its northwest, Ang Thong (50.6 km, 53.8 km) in its north.
4) Ang Thong (Wat Chanthraram) which has its territory in contact to Ayutthaya (53.8 km, 50.6 km) in its south, Saraburi (68 km, 61.8 km) in its east, Lop Buri (39.2 km, 39.7 km) in its northeast, Suphan Buri (52.6 km, 50.4 km) in its west, Sing Buri (46.4 km, 46 km) in its north.
5) Sing Buri (Wat Salakodom) which has its territory in contact to Ang Thong (46 km, 46.4 km) in its south, Lop Buri (36.7 km, 38.7 km) in its east, Suphan Buri (88.2 km, 88.6 km) in its southwest, Chai Nat (73.5 km, 54.4 km) in its west.
6) Nonthaburi (Wat Sao Thong Hin) which has its territory in contact to Bangkok (20.1 km, 18.3 km) in its south, Pathum Thani (29.9 km, 30.5 km) in its east, Nakhon Pathom (51 km, 52.7 km) in its west, Ayutthaya (72.4 km, 69.2 km) in its north.
7) Pathum Thani (Wat Bua Kaew Gaysorn) which has its territory in contact to Bangkok (49.3 km, 47.9 km) in its south, Nakhon Nayok (106 km, 105 km) in its east, Saraburi (93.6 km, 96.6 km) in its northeast, Nonthaburi (30.5 km, 29.9 km) in its west, Ayutthaya (50.5 km, 51.2 km) in its north.
8) Nakhon Pathom (Wat Phra Pathom Chedi) which has its territory in contact to Samut Sakhon (35.3 km, 34.4 km) in its south, Nonthaburi (52.7 km, 51 km)in its east, Ayutthaya (117 km, 114 km) in its northeast, Suphan Buri (90.6 km, 90 km) in its north.
9) Suphan Buri (Wat Pa La Lai) which has its territory in contact to Nakhon Pathom (90 km, 90.6 km) in its south, Ayutthaya (68.5 km, 68.4 km) in its southeast, Ang Thong (50.4 km, 52.6 km) in its east, Sing Buri (88.6 km, 88.2 km) in its northeast, Chai Nat (109 km, 111 km) in its north.
10) Nakhon Nayok (Wat Pramanee) which has its territory in contact to Bangkok (119 km, 115 km) in its southwest, Pathum Thani (105 km, 106 km) in its west, Saraburi (72.4 km, 71 km) in its north.
11) Bangkok (Wat Phra Si Rattana Satsadaram) which has its territory in contact to Samut Prakan (35 km, 34.3 km) in its south, Nakhon Nayok (115 km, 119 km) in its northeast, Samut Sakhon (66.7 km, 64.4 km) in its southwest, Nakhon Pathom (53.2 km, 52.4 km) in its west, Nonthaburi (18.3 km, 20.1 km) in its northwest, Pathum Thani (47.9 km, 49.3 km) in its north.
12) Samut Prakan (Wat Bang Phli Yai Klang) which has its territory in contact to Bangkok (34.3 km, 35 km) in its north.
13) Samut Sakhon (Wat Lak Si Rat Samoson) which has its territory in contact to Bangkok (64.4 km, 66.7 km) in its east, Samut Songkhram (26.8 km, 26.9 km) in its southwest, Nakhon Pathom (34.4 km, 35.3 km) in its north.
14) Samut Songkhram (Wat Phetsamut) which has its territory in contact to Samut Sakhon (26.9 km, 26.8 km) in its east.
15) Chai Nat (Wat Thammamun) which has its territory in contact to Suphan Buri (111 km, 109 km) in its south, Sing Buri (54.4 km, 73.5 km) in its east.

D. Eastern Region

The eastern region includes seven cities, i.e. Prachin Buri, Trat, Sa Kaeo, Chon Buri, Chachoengsao, Rayong, and Chanthaburi. The details of these cities are shown below:

1) Prachin Buri (Wat Kaew Phichit) which has its territory in contact to Chachoengsao (77.6 km, 76.8 km) in its south, Sa Kaeo (116 km, 117 km) in its east.
2) Trat (Wat Ta Som) which has its territory in contact to Chanthaburi (60.9 km, 61.2 km) in its north.
3) Sa Kaeo (Wat nakorndham) which has its territory in contact to Chanthaburi (157 km, 157 km) in its south, Chachoengsao (148 km, 147 km) in its west, Prachin Buri (117 km, 116 km) in its northwest.
4) Chon Buri (Wat Chong Samae San) which has its territory in contact to Rayong (47.8 km, 47.9 km) in its southeast, Chanthaburi (158 km, 156 km) in its east, Chachoengsao (133 km, 135 km) in its north.
5) Chachoengsao (Wat Sothon Worawiharn) which has its territory in contact to Chanthaburi (191 km, 191 km) in its south, Sa Kaeo (147 km, 158 km) in its east, Prachin Buri (76.8 km, 77.6 km) in its northeast, Chon Buri (135 km, 133 km) in its southwest.

6) Rayong (Wat Pa Pradu) which has its territory in contact to Chanthaburi (108 km, 108 km) in its east, Chon Buri (47.9 km, 47.8 km) in its north.
7) Chanthaburi (Wat Yothanimit) which has its territory in contact to Trat (61.2 km, 60.9 km) in its southeast, Rayong (108 km, 108 km) in its west, Chachoengsao (191 km, 191 km) in its northwest, Sa Kaeo (157 km, 157 km) in its north.

E. Northeast Region

The northeast region includes twenty cities: Chaiyaphum, Udon Thani, Nong Bua Lam Phu, Khon Kaen, Maha Sarakham, Kalasin, Sakon Nakhon, Yasothon, NakhonRatchasima, Loei, Nong Khai, Nakhon Phanom, Mukdahan, Amnat Charoen, Ubon Ratchathani, Buri Ram, Bueng Kan, Surin, Si Sa Ket and Roi Et. The details of these cities are given as follow:

1) Chaiyaphum (Wat Song Sila) which has its territory in contact to NakhonRatchasima (122 km, 121 km) in its south, Khon Kaen (123 km, 123 km) in its east.
2) Udon Thani (Wat Matchimawat) which has its territory in contact to Kalasin (190 km, 190 km) in its south, Sakon Nakhon (164 km, 164 km) in its east, Khon Kaen (121 km, 122 km) in its southwest, Nong Bua Lam Phu (80.4 km, 80.4 km) in its west, Loei (218 km, 219 km) in its northwest, Nong Khai (56.7 km, 57.6 km)in its north.
3) Nong Bua Lam Phu (Wat Tumsuwannakhuha) which has its territory in contact to Khon Kaen (178 km, 188 km) in its south, Udon Thani (80.4 km, 80.4 km) in its east, Loei (202 km, 202 km) in its west.
4) Khon Kaen (Wat thatkhonkaen) which has its territory in contact to Buri Ram (138 km, 139 km) in its south, Maha Sarakham (72.6 km, 62.9 km) in its southeast, Kalasin (62.3 km, 62.3 km) in its east, Udon Thani (122 km, 121 km) in its northeast, Nakhon Ratchasima (190 km, 190 km) in its southwest, Chaiyaphum (123 km, 123 km) in its west, Loei (266 km, 266 km) in its northwest, Nong Bua Lam Phu (188 km, 178 km) in its north.
5) Maha Sarakham (Wat Charoen Phon) which has its territory in contact to Surin (202 km, 193 km) in its south, Roi Et (53.2 km, 48.7 km) in its east, Buri Ram (117 km, 113 km) in its southwest, Khon Kaen (62.9 km, 72.6 km) in its west, Kalasin (22.9 km, 22.2 km) in its north.
6) Kalasin (Wat Klang) which has its territory in contact to Roi Et (47.3 km, 47.3 km) in its south, Mukdahan (167 km, 166 km) in its east, Sakon Nakhon (132 km, 133 km) in its northeast, Maha Sarakham (22.2 km, 22.9 km) in its southwest, Khon Kaen (62.3 km , 62.3 km) in its west, Udon Thani (190 km, 190 km) in its north.
7) Sakon Nakhon (Wat Phra That Choeng Chum) which has its territory in contact to Kalasin (133 km, 132 km) in its south, Mukdahan (118 km, 121 km) in its southeast, Nakhon Phanom (95.6 km, 95.5 km) in its east, Udon Thani (164 km, 164 km) in its west, Nong Khai (219 km, 219 km) in its northwest, Bueng Kan (191 km, 190 km) in its north.
8) Yasothon (Wat Ban Po) which has its territory in contact to Si Sa Ket (34.1 km, 34.4 km) in its south, Ubon Ratchathani (74.2 km, 74.2 km) in its southeast, Amnat Charoen (111 km, 111 km) in its east, Roi Et (140 km, 140 km) in its west, Mukdahan (187 km, 187 km) in its north.
9) NakhonRatchasima (Wat Phra NaraiMaharaj Woraviharn) which has its territory in contact to Buri Ram (132 km, 132 km) in its east, Chaiyaphum (121 km, 122 km) in its northwest, Khon Kaen (190 km, 190 km) in its north.
10) Loei (Wat Phra That Si Song Rak) which has its territory in contact to Khon Kaen (266 km, 266 km) in its south, Nong Bua Lam Phu (202 km, 202 km) in its southeast, Udon Thani (219 km, 218 km) in its east, Nong Khai (273 km, 261 km) in its northeast.
11) Nong Khai (Wat Pho Chai) which has its territory in contact to Udon Thani (57.6 km, 56.7 km) in its south, Sakon Nakhon (219 km, 219 km) in its southeast, Bueng Kan (139 km, 140 km) in its east, Loei (261 km, 273 km) in its west.
12) Nakhon Phanom (Wat Phra Pathom Chedi) which has its territory in contact to Mukdahan (108 km, 103 km) in its south, Sakon Nakhon (95.5 km, 95.6 km) in it west, Bueng Kan (177 km, 177 km) in it north.
13) Mukdahan (Wat Sriboonreung) which has its territory in contact to Yasothon (187 km, 187 km) in it south, Amnat Charoen (88.7 km, 88.7 km) in it southeast, Roi Et (163 km, 172 km) in its southwest, Kalasin (166 km, 167 km) in it west, Sakon Nakhon (121 km, 118 km) in its northwest, Nakhon Phanom (103 km, 108 km) in its north.
14) Amnat Charoen (The Buddha Utthayan and Phra Mongkhon Ming Muang) which has its territory in contact to Ubon Ratchathani (80.4 km, 80.3 km) in its south, Yasothon (111 km, 111 km) in its west, Mukdahan (88.7 km, 88.7 km) in its north.
15) Ubon Ratchathani (Wat Mahawanaram) which has its territory in contact to Si Sa Ket (66.2 km, 66.8 km) in its west, Yasothon (74.2 lm., 74.2 km) in its northwest, Amnat Charoen (80.3 km, 80.4 km) in its north.
16) Buri Ram (Wat Hong) which has its territory in contact to Surin (138 km, 138 km) in its east, Maha Sarakham (113 km, 117 km) in its northeast, NakhonRatchasima (132 km, 132 km) in its west, Khon Kaen (139 km, 138 km) in its north.
17) Bueng Kan (Wat Ta Krai) which has its territory in contact to Sakon Nakhon (190 km, 191 km) in its south, Nakhon Phanom (177 km, 177 km) in its southeast, Nong Khai (140 km, 139 km) in its west.
18) Surin (Wat Buraparam) which has its territory in contact to Si Sa Ket (106 km, 106 km) in its east, Buri Ram (138 km, 138 km) in its west, Maha Sarakham (193 km, 202 km) in its northwest, Roi Et (147 km, 152 km) in its north.
19) Si Sa Ket (Wat Maha Phuttharam) which has its territory in contact to Ubon Ratchathani (65.8 km, 66.2 km) in its east, Surin (106 km, 106 km) in its

west, Roi Et (149 km, 153 km) in its northwest, Yasothon (34.4 km, 34.1 km) in its north.

20) Roi Et (Wat Sa Thong) which has its territory in contact to Surin (152 km, 147 km) in its south, Si Sa Ket (153 km, 149 km) in its southeast, Yasothon (140 km, 140 km) in its east, Mukdahan (172 km, 163 km) in its northeast, Maha Sarakham (48.7 km, 53.2 km) in its west, Kalasin (47.3 km, 47.3 km) in its north.

F. Southern & Western Region

The southern & western region includes nineteen cities: Tak, Yala, Narathiwat, Kanchanaburi, Ratchaburi, Phetchaburi, Prachuap Khiri Khan, Chumphon, Ranong, Surat Thani, Phangnga, Phuket, Krabi, Trang, Nakhon Si Thammarat, Phatthalung, Songkhla, Pattani and Satun. The details of these cities are provided below:

1) Tak (Wat Mani Banphot Worawihan) which is in contact to Kanchanaburi (430 km, 426 km) in its south.
2) Yala (Wat Kuhaphimuk) which has its territory in contact to Narathiwat (91.7 km, 85.4 km) in its east, Songkhla (83.5 km, 83.2 km) in its northwest, Pattani (43 km, 46.3 km) in its north.
3) Narathiwat (Wat Khao Kong) which has its territory in contact to Yala (85.4 km, 91.7 km) in its east, Pattani (106 km, 105 km) in its north.
4) Kanchanaburi (Wat Chai Chumphon Chana Songkhram) which has its territory in contact to Ratchaburi (86.9 km, 87.3 km) in its south, Tak (426 km, 430 km) in its north.
5) Ratchaburi (Wat Mahathat) which has its territory in contact to Phetchaburi (54.8 km, 56.6 km) in its south, Kanchanaburi (87.3 km, 86.9 km) in its north.
6) Phetchaburi (Wat Khaotakhrao) which has its territory in contact to Prachuap Khiri Khan (86.3 km, 86 km) in its south, Ratchaburi (56.6 km, 54.8 km) in its north.
7) Prachuap Khiri Khan (Wat Huay Mongkol) which has its territory in contact to Chumphon (282 km, 283 km) in its south, Phetchaburi (86 km, 86.3 km) in its north.
8) Chumphon (Wat Chumphon Rangsan) which has its territory in contact to Surat Thani (183 km, 189 km) in its south, Ranong (119 km, 118 km) in its east, Prachuap Khiri Khan (283 km, 282 km) in its north.
9) Ranong (Wat Suwan Khiri Wihan) which has its territory in contact to Phangnga (232 km, 232 km) in its south, Surat Thani (216 km, 216 km) in its southeast, Chumphon (118 km, 119 km) in its east.
10) Surat Thani (Wat Thamma Bucha) which has its territory in contact to Nakhon Si Thammarat (147 km, 152 km) in its south, Krabi (164 km, 164 km) in its southwest, Phangnga (150 km, 153 km) in its west, Ranong (216 km, 216 km) in its northwest, Chumphon (189 km, 183 km) in its north.
11) Phangnga (Wat Prachum Yothi) which has its territory in contact to Phuket (67 km, 69 km) in its south, Krabi (81.8 km, 80.3 km) in its east, Surat Thani (153 km, 150 km) in its northeast, Ranong (232 km, 232 km) in its north.
12) Phuket (Wat Phra Thong) which has its territory in contact to Phangnga (69 km, 67 km) in its north.
13) Krabi (Wat Kaew Korawararam) which has its territory in contact to Trang (134 km, 134 km) in its south, Nakhon Si Thammarat (172 km, 172 km) in its east, Phangnga (80.3 km, 81.8 km) in its northwest, Surat Thani (164 km, 164 km) in its north.
14) Trang (Wat Nikhom Prathip) which has its territory in contact to Satun (158 km, 160 km) in its south, Phatthalung (75.4 km, 75.1 km) in its east, Krabi (134 km, 134 km) in its northwest, Nakhon Si Thammarat (122 km, 121 km) in its north.
15) Nakhon Si Thammarat (Wat Phra Mahathat) which has its territory in contact to Phatthalung (116 km, 115 km) in its south, Trang (121 km, 122 km) in its southwest, Krabi (172 km, 172 km) in its west, Surat Thani (152 km, 147 km) in its northwest.
16) Phatthalung (Wat Pa Khom) which has its territory in contact to Songkhla (160 km, 158 km) in its south, Trang (75.1 km, 75.4 km) in its west, Nakhon Si Thammarat (115 km, 116 km) in its north.
17) Songkhla (Wat Na Thawi) which has its territory in contact to Yala (83.2 km, 83.5 km) in its south, Pattani (66.9 km, 74.9 km) in its southeast, Satun (151 km, 155 km) in its west, Phatthalung (158 km, 160 km) in its north.
18) Pattani (Wat Mut Itthrapi) which has its territory in contact to Narathiwat (105 km, 106 km) in its south, Yala (46 km, 43 km) in its southwest, Songkhla (74.9 km, 66.9 km) in its west.
19) Satun (Wat Chanathip Chalerm) which has its territory in contact to Songkhla (155 km, 151 km) in its east, Trang (160 km, 158 km) in its north.

V. Experiments and Results

For each region, this paper will make an experiment by repeating AAA for eight runs based on all combinations of the two input parameters' values:

1) Map's rotation degree (0, 90, 180 or 270) and
2) Map image (original or mirror).

In each region, NN will be repeated for four runs based on four different starting cities; these starting cities used in NN are same to the northernmost cities of the four map' rotation degrees in AAA. For example, in the northern region, the northernmost cities of the Thailand's map rotated with 0, 90, 180 and 270 degrees are Chiang Rai, Nan, Uttaradit and Mae Hong Son, respectively; therefore, the four runs of NN will start its path by these cities. The technique to transform the map into the mirror image cannot make any difference for NN; this is the reason why NN will be repeated for only four runs instead of eight. AAA can be operated both by hand and by a personal computer. In order to compare both solution values and computational times of AAA algorithm and NN algorithm, this paper will operate both algorithms via the same personal computer in every problem instance. The AAA and NN algorithms are both

coded in Java on a Core 2 Duo processor 2.67 GHz with 4.00 GB of RAM PC computer.

Tables I to VI presents the round-trip's total distances in km of the six problem instances generated from AAA using the rotation degrees of 0, 90, 180 and 270 and the images of original and mirror. Moreover, the computational times in seconds are given in the parentheses. These results are then compared to those of NN. The best result given by each algorithm is printed in bold. To present the best round-trip routes generated from these both algorithms, it is simpler to represent the city by the city' number as mentioned prior in Section IV, e.g. Lamphun is numbered as 1, Phrae is numbered as 2, Lampang is numbered as 3, and so on.

TABLE I. DISTANCES AND CPU TIMES OF NORTHERN REGION

Degree	Original image	Mirror image	NN
0	1487.1 (0.003)	1535.7 (0.002)	1443.5 (0.006)
90	1582.1 (0.003)	1535.7 (0.002)	1658.1 (0.007)
180	1487.1 (0.002)	1535.7 (0.003)	1489.8 (0.007)
270	1534.4 (0.002)	1489.8 (0.002)	1772.5 (0.006)

For the northern region, there are two best round-trip routes found by AAA which consume the distance of 1487.1 km. These routes are the route of these cities' orders of (6, 7, 8, 9, 2, 3, 1, 5, 4, and 6) and (9, 2, 3, 1, 5, 4, 6, 7, 8, and 9). The best round-trip route found by NN returning 1443.5 km is the route of the cities' order of (6, 7, 8, 2, 9, 3, 1, 5, 4, and 6). Thus, in the northern region, NN win AAA.

TABLE II. DISTANCES AND CPU TIMES OF UPPER CENTRAL REGION

Degree	Original image	Mirror image	NN
0	819.2 (0.002)	792.8 (0.003)	865.8 (0.006)
90	748.5 (0.002)	964.2 (0.002)	759.3 (0.006)
180	794.4 (0.002)	818.3 (0.003)	841.2 (0.007)
270	953.9 (0.002)	853.3 (0.003)	839.5 (0.006)

For the upper central region, the best round-trip route found by AAA returning 748.5 km is the route of this cities' order: (5, 4, 6, 1, 2, 7, 3, and 5). The best round-trip route found by NN returning 759.3 km is the route of the cities' order: (5, 3, 7, 2, 1, 4, 6, and 5).

TABLE III. DISTANCES AND CPU TIMES OF LOWER CENTRAL REGION

Degree	Original image	Mirror image	NN
0	912.8 (0.004)	895.5 (0.004)	1044.1 (0.009)
90	1070.0 (0.003)	1047.8 (0.004)	1042.1 (0.009)
180	962.4 (0.004)	996.4 (0.004)	966.4 (0.008)
270	1042.4 (0.004)	1040.9 (0.003)	1057.5 (0.008)

For the lower central region, the best round-trip route found by AAA returning 895.5 km is the route of this cities' order: (2, 5, 15, 9, 8, 13, 14, 11, 12, 6, 7, 10, 1, 3, 4, and 2). The best round-trip route found by NN returning 966.4 km is the route of the cities' order: (14, 13, 8, 6, 11, 12, 7, 3, 4, 2, 5, 15, 9, 1, 10, and 14).

TABLE IV. DISTANCES AND CPU TIMES OF EASTERN REGION

Degree	Original image	Mirror image	NN
0	759.9 (0.003)	747.9 (0.002)	797.0 (0.007)
90	759.9 (0.002)	747.9 (0.002)	797.0 (0.006)
180	743.6 (0.002)	763.6 (0.002)	743.6 (0.006)
270	759.9 (0.003)	747.9 (0.002)	747.9 (0.006)

For the eastern region, the best round-trip route found by AAA and the route found by NN are same; it is the route of this cities' order: (2, 7, 6, 4, 5, 1, 3, and 2) which consumes the distance of 743.6 km.

TABLE V. DISTANCES AND CPU TIMES OF NORTHEAST REGION

Degree	Original image	Mirror image	NN
0	2600.5 (0.004)	2993.3 (0.004)	2592.0 (0.009)
90	3061.5 (0.004)	2701.9 (0.004)	2949.2 (0.009)
180	2813.4 (0.005)	2720.5 (0.004)	2956.0 (0.009)
270	2900.7 (0.005)	2446.9 (0.004)	2294.3 (0.008)

For the northeast region, the best round-trip route found by AAA returning 2446.9 km is the route of this cities' order: (10, 4, 1, 9, 16, 18, 19, 15, 14, 13, 8, 20, 6, 5, 7, 12, 17, 11, 2, 3, and 10). The best round-trip route found by NN returning 2294.3 km is the route of the cities' order: (10, 3, 2, 11, 17, 12, 7, 13, 14, 15, 19, 8, 18, 16, 20, 6, 5, 4, 1, 9, and 10).

TABLE VI. DISTANCES AND CPU TIMES OF SOUTHERN & WESTERN REGION

Degree	Original image	Mirror image	NN
0	3735.6 (0.004)	3761.9 (0.004)	4224.3 (0.009)
90	3728.8 (0.004)	3768.5 (0.004)	4132.3 (0.008)
180	3728.8 (0.004)	4373.3 (0.004)	4132.3 (0.008)
270	3735.6 (0.004)	3761.9 (0.004)	4224.3 (0.009)

For the southern & western region, there are two best round-trip routes found by AAA that equally return 3728.8 km. These routes are in these cities' orders of (2, 17, 19, 14, 13, 12, 11, 9, 8, 7, 6, 5, 4, 1, 10, 15, 16, 18, 3, and 2) and (3, 2, 17, 19, 14, 13, 12, 11, 9, 8, 7, 6, 5, 4, 1, 10, 15, 16, 18, and 3). There are also two best round-trip routes found by NN equally returning 4132.3 km. These routes are (2, 18, 17, 19, 16, 14, 15, 10, 11, 12, 13, 9, 8, 7, 6, 5, 4, 1, 3, and 2) and (3, 2, 18, 17, 19, 16, 14, 15, 10, 11, 12, 13, 9, 8, 7, 6, 5, 4, 1, and 3).

Based on the data from the six tables above, in the performance comparison between AAA and NN, AAA performs better than NN for three problem instances, i.e. upper central region, lower central region, and southern & western region. NN performs better than AAA for two problem instances, i.e. northern region and northeast region. For eastern region, they perform equally. Thus, AAA outperforms NN in counting the number of the better results from these problem instances.

Later on, Table VII compares the best result taken from AAA, the best result taken from NN and the lower bound of the optimal solution value (LB) for each problem instance. The result that wins in the comparison between AAA and NN will be printed in bold. The computation for the lower bound of the total distance of the best roundtrip (LB) of each problem instance is given as follows: for N cities including city 1 through N, the lower bound is the summation of the distance of the shortest path between city 1 and any other cities in both directions, the distance of the shortest path between city 2 and any other cities in both directions, and so on, until the

distance of the shortest path between city *N* and any other cities in both directions.

The information shown in Table VII is then summarized in Table VIII which presents the percentage variance between the best result of each algorithm and LB for each problem instance. The result that wins in the comparison will be printed in bold. AAA performs better than NN on three problem instances, i.e. the upper central region, lower central region and southern & western region. NN performs better than AAA on two problem instances, i.e. the northern region and northeast region. For the eastern region, they both perform equally.

TABLE VII. BEST RESULTS (IN KM) OF PROBLEM INSTANCES

Instance	LB	AAA	NN
Northern	958.1	1487.1	1443.5
Upper Central	505.5	748.5	759.3
Lower Central	581.3	895.5	966.4
Northeast	1639.3	2446.9	2294.3
Eastern	593.6	743.6	743.6
Southern & Western	1971.7	3728.8	4132.3

TABLE VIII. PERCENTAGE VARIANCE BETWEEN BEST RESULT AND LB

Instance	AAA	NN
Northern	55%	51%
Upper Central	48%	50%
Lower Central	54%	66%
Northeast	49%	40%
Eastern	25%	25%
Southern & Western	89%	110%

Based on the information from Table VIII, this paper constructs the hypothesis test of H0: Mean of the differences between the percentage variances from LBs of AAA and the percentage variances from LBs of NN equals zero versus H1: that is less than zero by MINITAB software using the significance level of 0.25. The Minitab software then returns the *p*-value of 0.226. Since, the *p*-value, i.e. 0.226, is less than 0.25, the null hypothesis is rejected and the conclusion of the hypothesis test's result is that the mean of the differences of the percentage variances from LBs of AAA and the percentage variances from LBs of NN is less than zero with the significance level of 0.25.

In terms of computational times, the results in Tables I to IV show that the AAA and NN algorithms both executes very fast. The highest CPU time per run of AAA is 0.005 seconds while the highest CPU time per run of NN is 0.009 seconds via a personal computer.

VI. CONCLUSION

This paper proposes Adjacent Area Algorithm (AAA), a problem-based heuristic, to construct the round-trip route for ATSP, inspired from a daily room's floor cleaning task of a housekeeper. Since ATSP is a generalized TSP, this heuristic can solve TSP as well. AAA starts with travelling from the northernmost city to the southernmost city of the country through the adjacent border cities in clockwise direction. After that, the heuristic constructs the trip from the southernmost city to one of its adjacent cities in the eight directions based on the predefined direction priorities; this procedure will be continuously repeated until every city has been visited, and the last visited city is the northernmost city. The test's results presented in this paper conclude that AAA performs better than NN algorithm. The computational time of AAA is also very fast.

REFERENCES

[1] B. A. Alsaalibi, M. B. Jelodar, and I. Venkat, "A comparative study between the nearest neighbor and genetic algorithms: A revisit to the traveling salesman problem," *International Journal of Computer Science and Electronics Engineering*, vol. 1, no. 1, pp. 34-38, 2013.

[2] M. R. Garey and D. S. Johnson, *Computers and Intractability: A Guide to the Theory of NP-Completeness*, New York: Macmillan Higher Education, ch. 2, 1979.

[3] W. Zhang and R. E. Korf, "A study of complexity transitions on the asymmetric traveling salesman problem," *Artificial Intelligence*, vol. 81, no. 1-2, pp. 223-239, 1996.

[4] N. Ascheuer, M. Fischetti, and M. Grotschel, "Solving the asymmetric travelling salesman problem with time windows by branch-and-cut," *Mathematical Programming*, vol. 90, no. 3, pp. 475-506, 2001.

[5] D. L. Miller and J. F. Pekny, "Exact solution of large asymmetric traveling salesman problems," *Science*, vol. 251, no. 4995, pp. 754-761, 1991.

[6] D. J. Rosenkrantz, R. R. Stearns, and P. M. Lewis, "An analysis of several heuristics for the traveling salesman problem," *SIAM Journal on Computing*, vol. 6, no. 3, pp. 563-581, 1977.

[7] J. Majumdar and A. K. Bhunia, "Genetic algorithm for asymmetric traveling salesman problem with imprecise travel times," *Journal of Computational and Applied Mathematics*, vol. 235, no. 9, pp. 3063-3078, 2011.

[8] M. Shaikh and M. Panchl, "Solving asymmetric travelling salesman problem using memetic algorithm," *International Journal of Emerging Technology and Advanced Engineering*, vol. 2, no. 11, pp. 634-639, 2012.

[9] I. Piriyaniti and P. Pongchairerks, "Variable neighbourhood search algorithms for asymmetric travelling salesman problem," *International Journal of Operational Research*, vol. 18, no. 2, pp. 157-170, 2013.

[10] S. Basu, "Tabu search implementation on traveling salesman problem and its variations: A literature survey," *American Journal of Operations Research*, India, pp. 163-173, 2012.

[11] Z. C. S. S. Hlaing and M. A. Khine, "Solving traveling salesman problem by using improved ant colony optimization algorithm," *International Journal of Information and Education Technology*, vol. 1, no. 5, pp. 404-409, 2011.

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