CHAPTER 4

Simulation Results and Case Studies

There are 2 subjects discussed in this chapter. The first one is the testing of the method for the p-center problem and facility location problem already presented in chapter 3 using the simulation data. The second part is the application of the presented method with the logistics network case study conducted in Chiang Mai and other 4 provinces in the Northern part of Thailand.

4.1 Simulation Results

Simulation results in this part have been applied to test the method efficiency demonstrated in Chapter 3 which has been separated into 2 parts: the information model for the p-center problem method efficiency testing and a section denoted to the location problem.

4.1.1 Simulation Results of P-center Problem

In testing the p-center problem method efficiency, we have tested both capacitated and uncapacitated cases by comparing the results from the method presented in [2] and the optimal solution from the branch and bound algorithm. The method presented by Albareda-Sambola [2] is similar to the one that we have presented. However, there is a slight difference in the 2 methods. That is to say, Albareda-Sambola [2] had solved the problem by bisection the real number line and used the Lagrangean relaxation. In the simulation, we have presented the randomized data. For each problem, it is in the form of client-node numbers equivalent to the candidate location numbers. Since the complexity of problem solving equals $mn^3log(mn)$ where m represents any number of candidate locations for facilities and n is the amount of client nodes. Therefore, it is enough to consider only the case where client numbers equal candidate facility numbers. If the number of clients and the amount of candidate locations for the facility vary in the problem, it is not difficult to adjust the problem size and make it equivalent by building the number of clients or candidate locations for the facility. If the amount of candidate facility locations is less than the customer number, the dummy facility will be created by setting a higher set-up cost in order that the facility will not be chosen. On the contrary, if the customer number is less than the candidate facility location, the dummy of clients will be built by setting the logistics expenses or the distance between the clients and the facility locations. Moreover, the value for dummy clients supply will be 0 so that it will not leave an effect on the results from the beginning system. In the simulation data for method testing, the information model in the number of clients equal to the number of facilities formed will be considered. The distance between the clients and the facility location have randomly been created in the range $[0, 50]$ for both uncapacitated and capacitated cases. Table 4.1 and 4.2 have presented test results for the uncapacitated problem. Table 4.1 demonstrates the time comparison in the problem solving of the method presented in Chapter 3 and that which was by presented [2]. The variables m, n in Column 1 of Table 4.1 and 4.2, they represent the amount of candidate locations for the facility and the amount of clients, respectively. The variable p in Column 2 from Tables 4.1 and 4.2 presents the amount of facility locations that will be opened. Min t, max t and avg t in Columns 3, 4 and 5 of Table 4.1 represent the period of time in the second with the least amount of time, the most amount of time and the average amount of time from 100 cases in the method presented in Chapter 3, respectively. Min t, max t and avg t in Columns 6, 7 and 8 of Table 4.1 demonstrate the least amount of time, the most amount of time and the average amount of time from 100 cases in problem solving by using the method presented by [2]. Table 4.2 shows the comparison percentages of the optimality gap between the method results presented in Chapter 3, the method presented by [2] and the optimal solution from the branch and bound algorithm. Min %, max % and avg % in Columns 3, 4 and 5 from Table 4.2 show the least optimality gap, the most optimality gap and the average optimality gap from 100 cases presented by the method in Chapter 3. Tables 4.3 and 4.4 present the results from the capacitated case. The information model of the distance between the clients and the facility in range $[0, 50]$, client supply in range $[0, 20]$ and the facility value in range $[50, 100]$ have been created in the capacitated case. Table 4.3 demonstrates the comparison of time in problem solving both from the method presented in Chapter 3 and the method presented by Albareda-Sambola [2]. All variables in Table 4.3 are in accordance with those of Table 4.1 and all variables in Table 4.4 in accordance with those of Table 4.2.

Table 4.1: Average CPU times of 100 random data sets in the uncapacitated case.

size		Time spent using the proposed method(s)			Time spent using method 3 given in [2] (s)			t-test for equality of means
m,n	p	min t	max t	avg t	min t	max t	avg t	p-value
50	5	4.597×10^{-5}	0.0312	0.0087	0.0229	0.0624	0.0312	3.0000×10^{-6}
50	10	0.0123	0.0468	0.0156	0.0270	0.0624	0.0468	7.4248×10^{-7}
50	15	0.0148	0.0468	0.0156	0.0309	0.0780	0.0468	8.7650×10^{-51}
50	20	0.0144	0.0468	0.0156	0.0326	0.0780	0.0468	1.0670×10^{-51}
100	10	0.0373	0.0936	0.0624	0.1005	0.2184	0.1716	1.6621×10^{-69}
100	20	0.0526	0.1560	0.0936	0.2184	0.1203	0.2184	2.4379×10^{-62}
100	30	0.0640	0.1560	0.1092	0.1388	0.3276	0.2496	9.5110×10^{-55}
100	50	0.0658	0.1560	0.1092	0.1437	0.3120	0.2652	5.5205×10^{-79}
500	50	5.1730	5.4288	4.8828	8.8873	10.0729	9.6751	7.4970×10^{-186}
500	100	5.5536	6.0840	5.9046	10.7593	11.2897	11.0042	2.4330×10^{-239}
500	150	6.6300	7.1448	6.9015	11.5549	12.7405	12.4347	2.3090×10^{-213}
500	200	7.4880	8.2369	7.9561	13.1929	14.3473	13.8824	1.2589×10^{-199}

Table 4.2: The percentage gap between solutions found and the optimal solution in the uncapacitated case.

size		The percentage gap using the proposed method(%)			The percentage gap using method 3 given in [2] (%)			t-test for equality of means
m,n	p	min %	max %	avg %	min %	max %	avg %	p-value
50	5	0.0000	3.0339	0.1389	0.0000	4.1125	0.1593	0.6914
50	10	0.0000	4.1942	0.0827	0.0000	4.1942	0.1526	0.3984
50	15	0.0000	4.3970	0.0562	0.0000	4.3970	0.0067	0.8618
50	20	0.0000	4.0071	0.9283	0.0000	4.0071	0.3970	0.5889
100	10	0.0000	9.1812	3.0878	0.0000	12.1491	4.1354	0.1279
100	20	0.0000	11.9220	3.0679	0.0000	11.9220	2.9341	0.8006
100	30	0.0000	11.2499	3.0199	0.0000	15.0339	3.0014	0.9730
100	50	0.0000	15.7710	5.2499	0.0000	14.3823	6.0095	0.3283
500	50	0.0000	17.0468	7.2184	0.0000	16.1159	7.5501	0.6670
500	100	0.0000	15.5630	9.2319	0.0000	15.6411	9.3462	0.8682
500	150	0.0000	16.1031	10.2265	0.0000	17.9902	10.7621	0.5041
500	200	0.0000	20.1152	10.9789	0.0000	20.5501	11.0052	0.9779

Table 4.3: Average CPU times of 100 random data sets in the capacitated case.

size		Time spent using the proposed method(s)			Time spent using method 3 given in [2] (s)			t-test for equality of means
m,n	p	min t	max t	avg t	min t	max t	avg t	p-value
50	5	7.9280	8.9420	8.5848	9.8201	11.5829	10.8357	8.8718×10^{-92}
50	10	10.5801	11.9997	11.3257	12.2661	13.2957	12.7372	3.7758×10^{-68}
50	15	11.9545	13.7017	13.1089	13.3737	20.4718	15.4735	1.5088×10^{-19}
50	20	13.6705	14.8093	14.2960	15.6810	20.6090	17.5951	1.0047×10^{-53}
100	10	100.6463	110.5853	107.2575	143.3517	151.0540	148.3112	2.8183×10^{-167}
100	20	104.7094	117.2238	106.8407	148.8308	155.5308	153.5285	8.5696×10^{-186}
100	30	108.7547	120.7513	118.2543	153.5853	161.7792	160.1656	2.0101×10^{-177}
100	50	111.2760	124.2551	120.8143	164.5497	178.9340	167.6020	1.6559×10^{-146}
400	40	338.6797	349.5060	345.2435	440.9172	469.1299	465.2630	2.9709×10^{-204}
400	80	351.6551	370.6991	363.9293	455.2858	478.5688	474.6541	8.0513×10^{-189}
400	120	362.1626	379.8909	371.3500	471.7572	493.4694	489.6892	2.7031×10^{-199}
400	150	380.1190	399.9593	387.1966	500.7537	529.0119	522.7482	6.3654×10^{-187}

Table 4.4: The percentage gap between solutions found and the optimal solution in the capacitated case.

size		The percentage gap using the proposed method(%)			The percentage gap using method 3 given in [2] (%)			t-test for equality of means
m,n	p	min %	max %	avg %	min %	max %	avg %	p-value
50	5	0.0000	19.2319	5.5630	0.0000	24.2942	7.3462	0.1064
50	10	0.0000	14.4505	3.1818	0.0000	15.9619	3.5132	0.5953
50	15	0.0000	18.0838	2.2638	0.0000	17.0046	3.4018	0.0827
50	20	0.0000	17.2290	4.1455	0.0000	17.7749	4.0760	0.9266
100	10	0.0000	23.9133	7.1361	0.0000	20.8173	5.2399	0.0797
100	20	0.0000	25.1524	5.8693	0.0000	27.8687	7.1233	0.2822
100	30	0.0000	26.8258	4.5797	0.0000	26.0844	5.1839	0.5925
100	50	0.0000	19.5383	7.5499	0.0000	23.3998	7.2400	0.7594
400	40	0.0000	35.9961	10.1450	0.0000	36.2599	10.4173	0.8773
400	80	0.0000	40.0782	12.8530	0.0000	39.8001	13.0497	0.9259
400	120	0.0000	37.4427	10.6221	0.0000	38.4314	10.9027	0.8791
400	150	0.0000	43.1067	10.3510	0.0000	44.9106	9.9448	0.8290

The t-test has been applied in order to compare the statistics acquired with the method from Chapter 3 with those acquired with the method from Albareda-Sambola [2] by using the average time result in terms of problem solving in both cases. In studying Tables 4.1 and 4.3 at the significance level of $\alpha = 0.01$ from both cases, it has been concluded that the method that we have presented can solve the sampled problems faster than the method presented by Albareda-Sambola [2]. Additionally, from the optimality gap comparison from Tables 4.2 and 4.4 at the significance level of $\alpha = 0.01$, it has shown that there had been slight differences in the results of the sampled problems both from the method mentioned in Chapter 3 and the one presented by Albareda-Sambola [2]. Consequently, it can be concluded that the method we have proposed takes less time in the result-seeking process from the sampled problems than the method presented by Albareda-Sambola [2] with not difference in the error value at the significance point of $\alpha = 0.01$.

4.1.2 Simulation Results of Facility Location Problem

The 3 information models have been randomly created by choosing 500 client nodes and 500 facility nodes in 100 data sets. Figures 4.1−4.6 present the relation between the average overall expenses of 100 data sets and the number of opening facilities. In case 1) balanced cost, the information in 100 cases has been randomized by using transportation costs between the clients and facilities in the range [0,10], set up costs of facilities in the range [5,50], the client supplies in the range [0,10] and the facility capacities in the range [5,50]. The results from Methods A, B and C in Chapter 3 have been presented in Figure 4.1. In case 2) higher set up cost, the information in 100 cases has been randomized by using transportation costs between the clients and facilities in the range [0,10], set up costs of facilities in the range [10,100], the client supplies in the range [0,10] and the facility capacities in the range [5,50]. The results from Methods A, B and C in Chapter 3 have been presented in Figure 4.2. In case 3) higher transportation, the information in 100 cases has been randomized by assessing the transportation costs between clients and facilities in the range [0,20], set up costs of facilities in the range [5,50], the client supplies in range the [0,10] and the facility capacities in the range [5,50]. The results from Methods A, B and C in Chapter 3 have been presented in Figure 4.3.

In studying the Figures 4.1−4.3, it can be summarized that the appropriate result for the method with the higher set-up cost is the small amount of opening facilities. On the contrary, if the information involves the higher transportation cost, the appropriate result will be the large amount of opening facilities. From the simulation data, the conclusion can be made that Method A is slightly better than the other 2 methods in terms of a higher set-up cost. Subsequently, we have compared the test results from the methods in terms of higher set-up costs. Next, we have compared the test results from the method and the optimal solution. In order to find the optimal solution, we used Program AIMMS, the instant program developed to create the problem model with CPLEX as the solver. The above mentioned program has helped to solve the problem and find the optimal solution.

Next, AIMMS, a modeling program with a CPLEX engine, was used to find the optimal solution for this problem. CPLEX can be executed with an optimal solution for most generated problems up to 200 demand points and 200 potential facility sites.

Due to limitations of CPLEX, test problems are randomly generated with that size in all 3 cases. Results obtained by the proposed methods are compared with solutions from CPLEX. Moreover, optimal solutions obtained by LP relaxation (LP bound) are compared with the solutions from proposed methods and CPLEX. Compared results can be seen in Figures 4.4-4.6 for problems generated with balanced costs, higher setup costs and higher transportation costs, respectively. The results of 200 demand and facility sites as seen in Figures 4.4-4.6 are similar to the results of 500 demand and facility sites as seen in Figures 4.1-4.3.

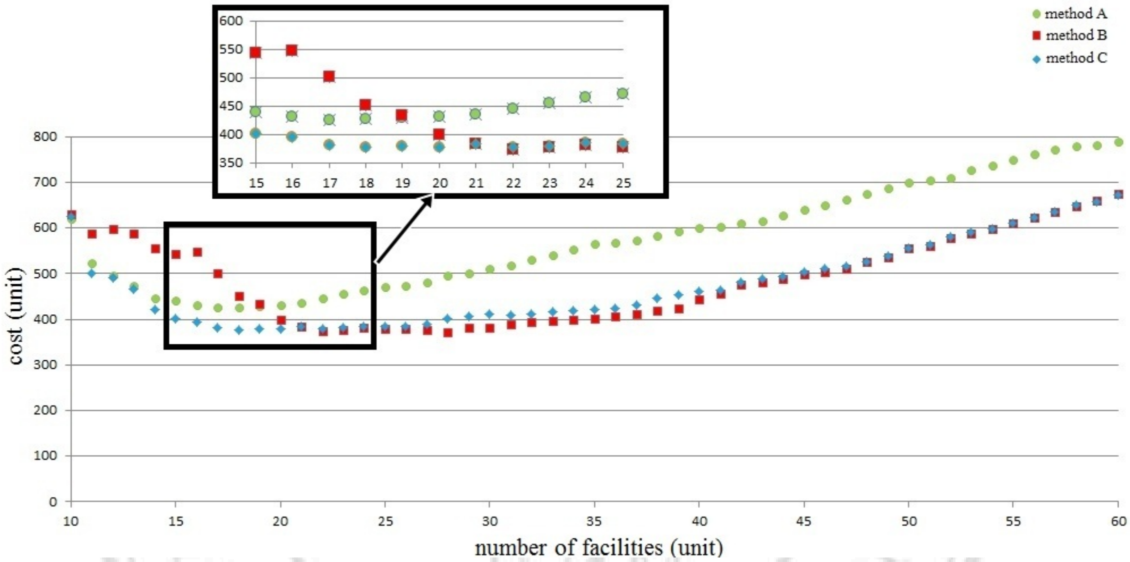

Figure 4.1: Total cost obtained from all 3 methods in terms of the problems with balanced cost.

4.2 Case Studies

This part will be divided into 2 minor classification. The first section is about testing the problem-size reduction method stated in Section 3.1 by using the case study of the transportation network system in Chiang Mai. The second section is about testing the facility location problem method presented in Section 3.3 by using the case study of the transportation network system both in Chiang Mai and the other 5 provinces in the Northern part of Thailand.

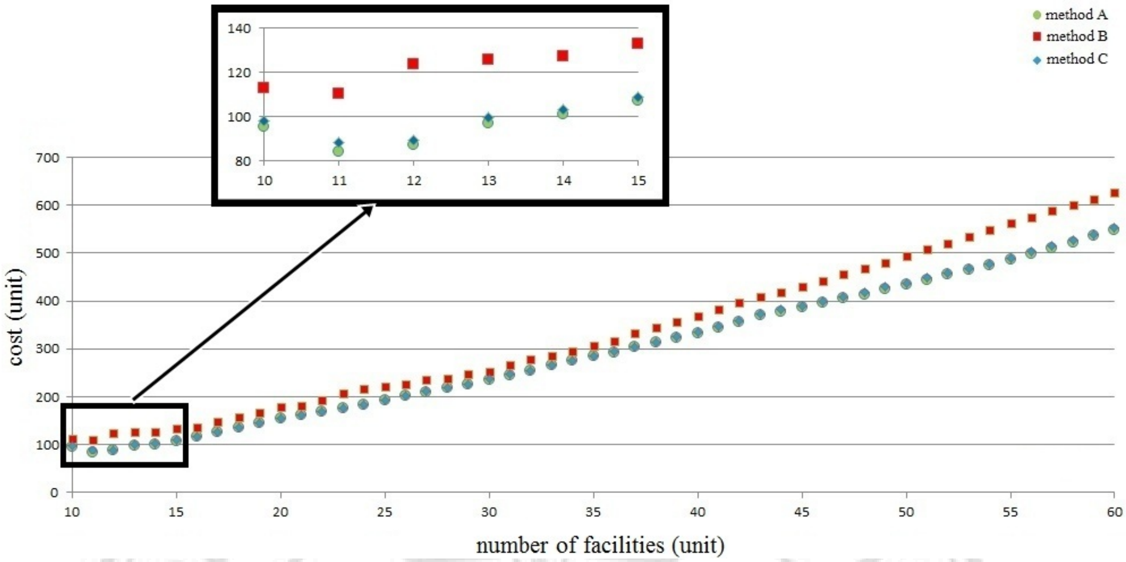

Figure 4.2: Total cost obtained from all 3 methods on problems with setup costs higher than transportation costs.

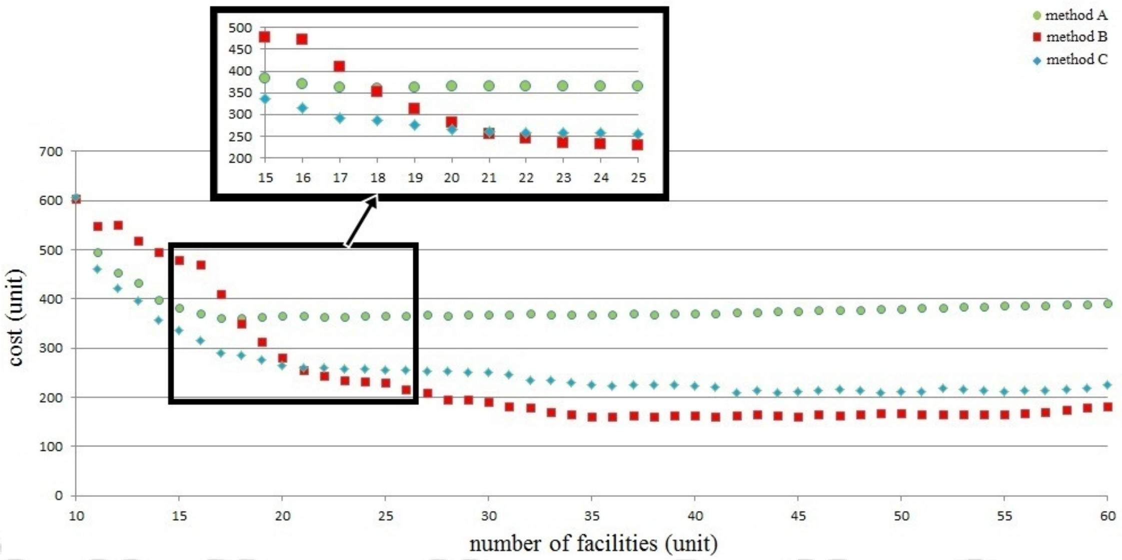

Figure 4.3: Total cost obtained from all 3 methods on problems with transportation costs higher than setup costs.

4.2.1 Case Study for Problem-size Reduction Method

In order to test the efficiency of the problem-size reduction method presented in Section 3.1, we apply the method to the data from Chiang Mai waste management records in 2012 which consists of 432 client node coordinates, the distances between adjacent nodes and the amount of waste from each client node. Note that the distances between each pair

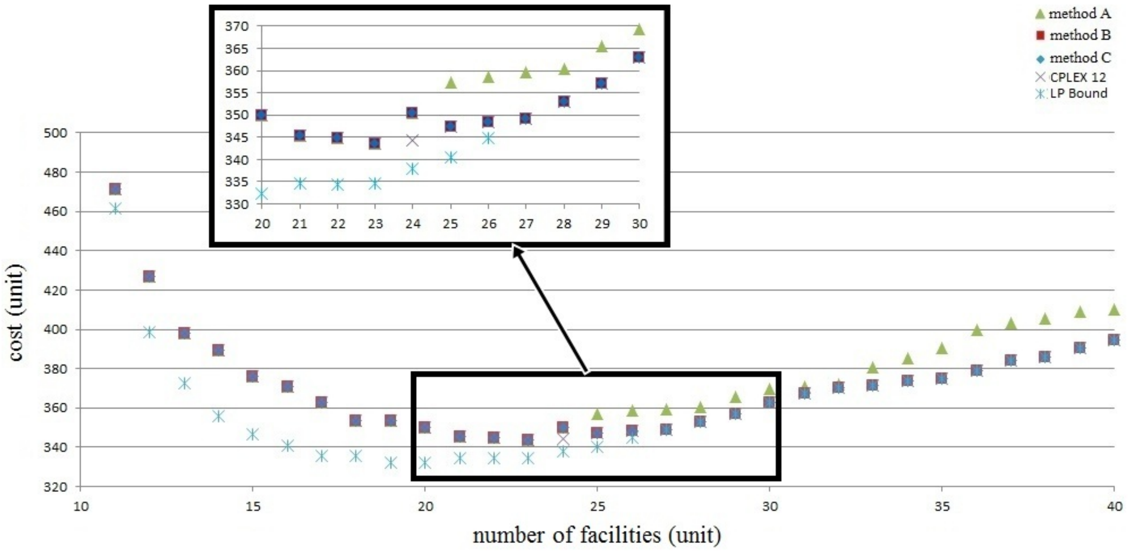

Figure 4.4: Total cost obtained from all 3 methods and CPLEX on problems with balanced costs.

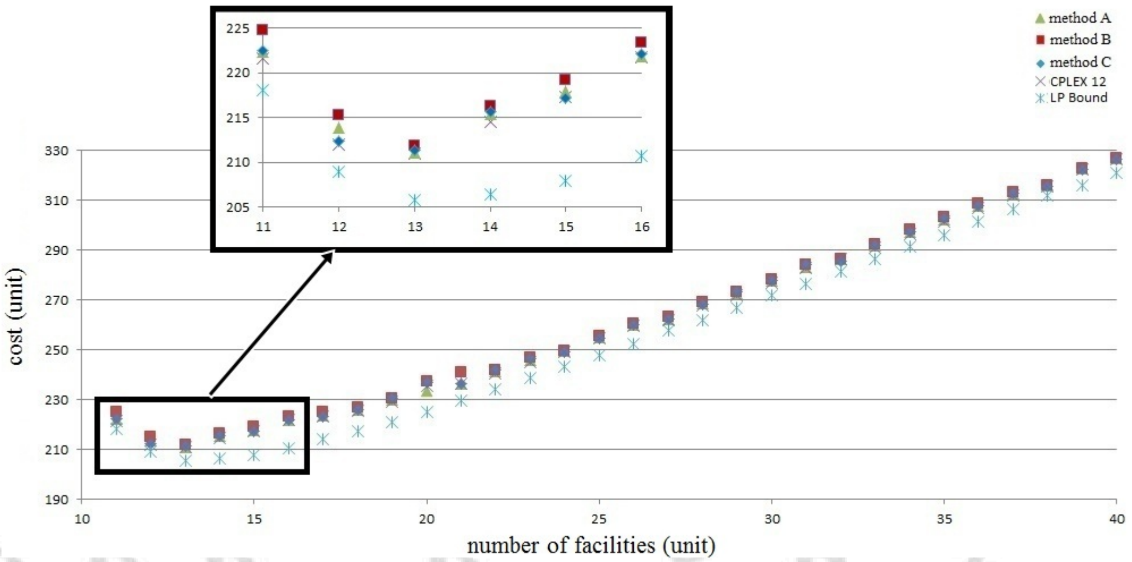

Figure 4.5: Total cost obtained from all 3 methods and CPLEX on problems with setup cost higher than transportation costs.

of nodes are calculated using Dijkstra's algorithm. From Chiang Mai Municipality data in 2012, Chiang Mai municipal waste has been gotten rid of twice a week or 104 times a year. The transportation cost depends on the truck's fuel consumption rate, varied fuel price, distance traveled and so on. For these particular reasons, the transportation cost is calculated from distances between each node and the fuel usage rate at 4.45 kms/litre with 10-year-average fuel price (in 2002−2012) at 27.99 baht/litre. The setup costs calculation

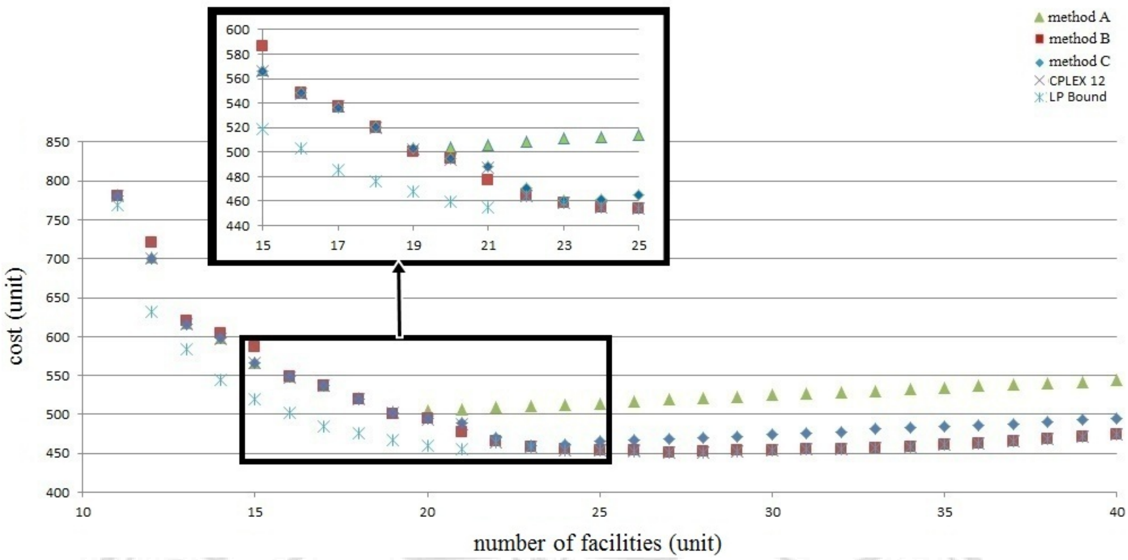

Figure 4.6: Total cost obtained from all 3 methods and CPLEX on problems with transportation cost higher than setup costs.

consist of the facility-construction cost and the land expense. The land cost is determined from the average land price in each area. We have considered the middle-size waste-management facilities with the capacity at 100 tons/day. The setup cost is calculated as the yearly present currency expense (Baht) by estimating the totals from the facilities with a 20-year break even point and a decade average inflation rate of 3.03 percent/year.

The method efficiency presented in Section 3.1 is represented by the comparison between optimal solutions of the problems before and after size reduction. The original 432 nodes in the Chiang Mai network before downsizing is shown in Figure 4.7. The mathematical model of this problem is formulated in AIMMS to obtain an optimal solution by CPLEX solver. Optimal solution results in 3 facilities with 3 client groups which are shown in Figure 4.8 (a). Figures 4.8 (b)-(d) demonstrate the client groups of facilities 1, 2 and 3, respectively. Then Chiang Mai city network is reduced into 2 cases: 1) removing nodes with degree 1, and 2) removing node with degrees 1 and 2. In the first case, the network has been downsizing to 345 nodes as in Figure 4.9. Figure 4.10 is the network with 200 nodes after downsizing by reducing the nodes with degrees 1 and 2 in the second case. Figures 4.11 (a) and 4.12 (a) present the optimal solutions of the Chiang Mai network after downsizing in both cases obtained by AIMMS. Figures 4.11 (b), (c) and (d) show the 3 optimal client groups which correspond to the optimal opening facilities in the first case network and Figures 4.12 (b), (c) and (d) are those in the second case network. The results of 3 sizes of Chiang Mai network are compared among each other in Table 4.5. First column shows the number of nodes in original network and 2 reducing networks. Second and third columns present the optimal number of opened facilities and the optimal expenses in baht/year, respectively.

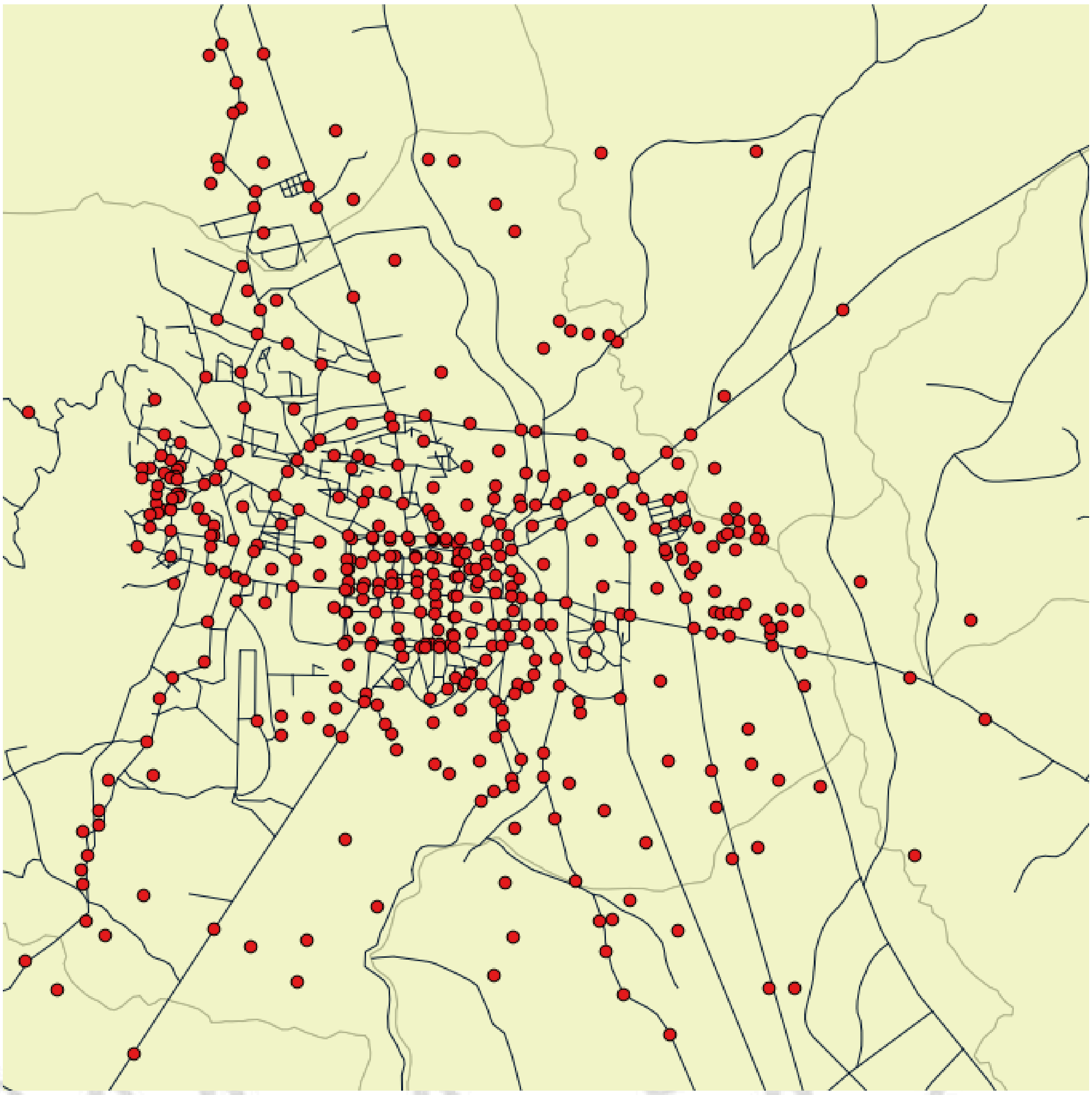

Figure 4.7: Original supply sites with 432 node-link in Chiang Mai city, Thailand.

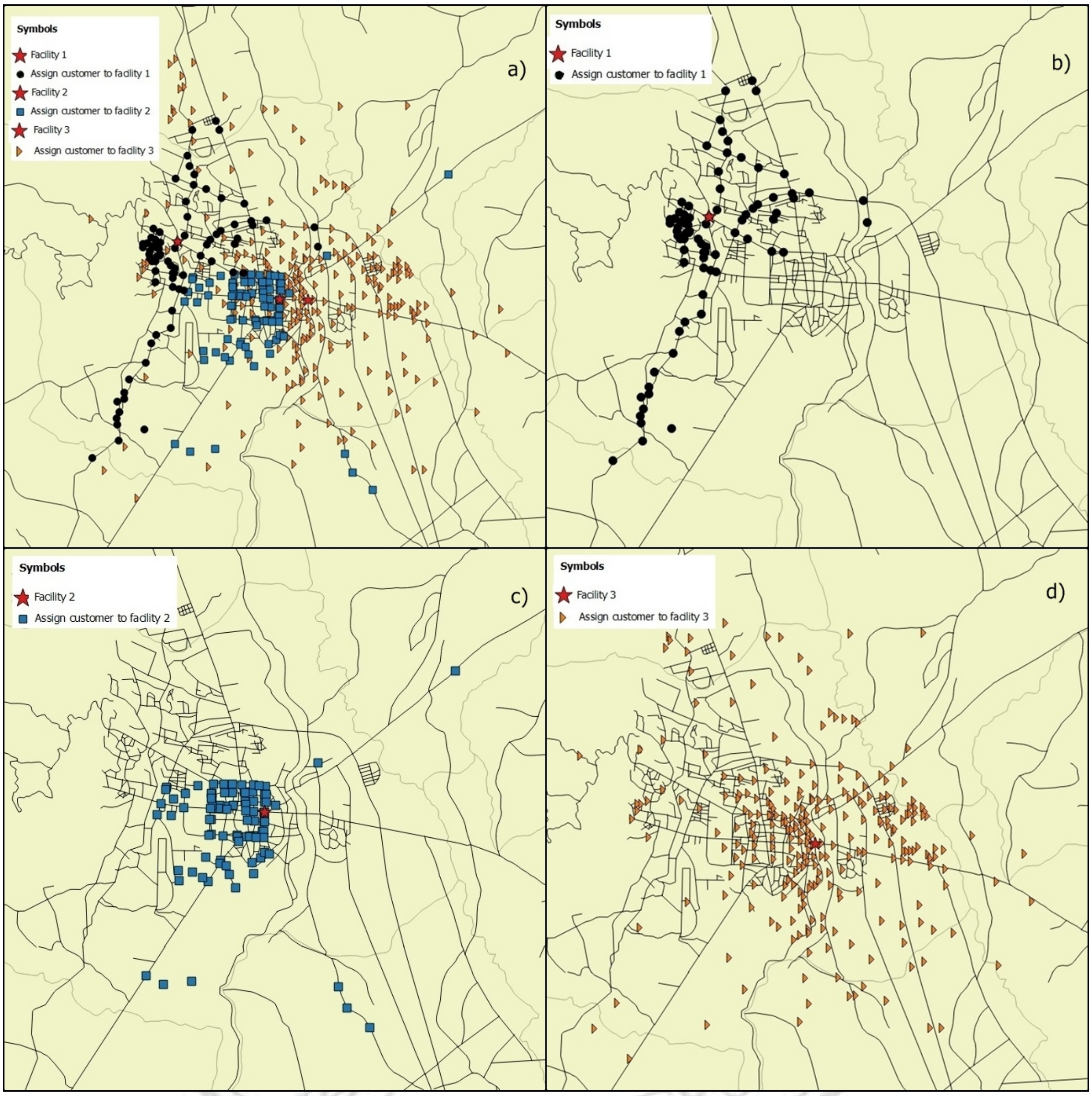

Figure 4.8: The 432 node network optimal solution before size reduction. a) 3 facilities and client groups b) client groups of facility 1 c) client groups of facility 2 d) client groups of facility 3.

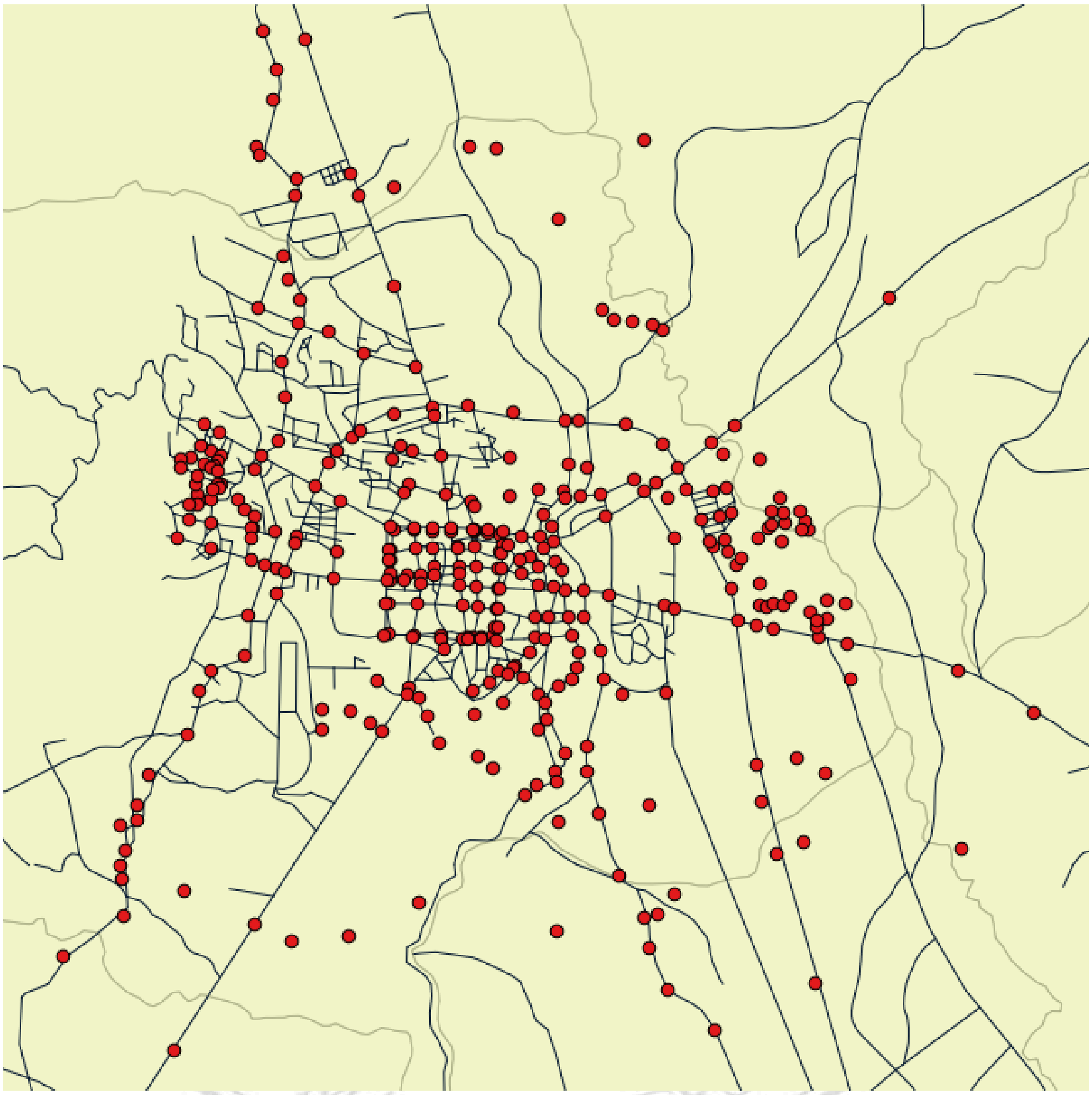

Figure 4.9: 345 supply sites with nodes of degree 1 removed in Chiang Mai city, Thailand.

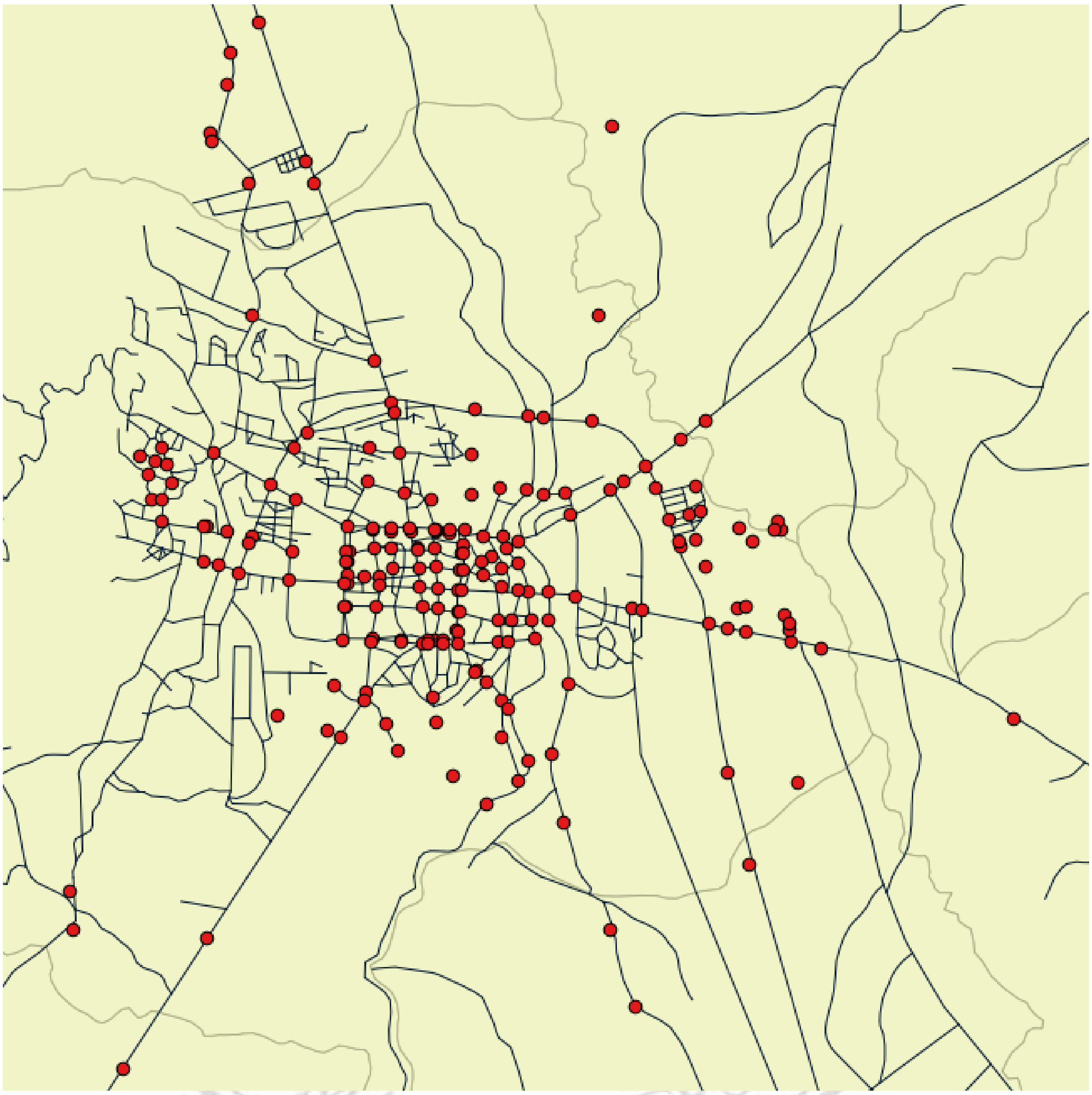

Figure 4.10: 200 supply sites with nodes of degree 1 and 2 removed in Chiang Mai city, Thailand.

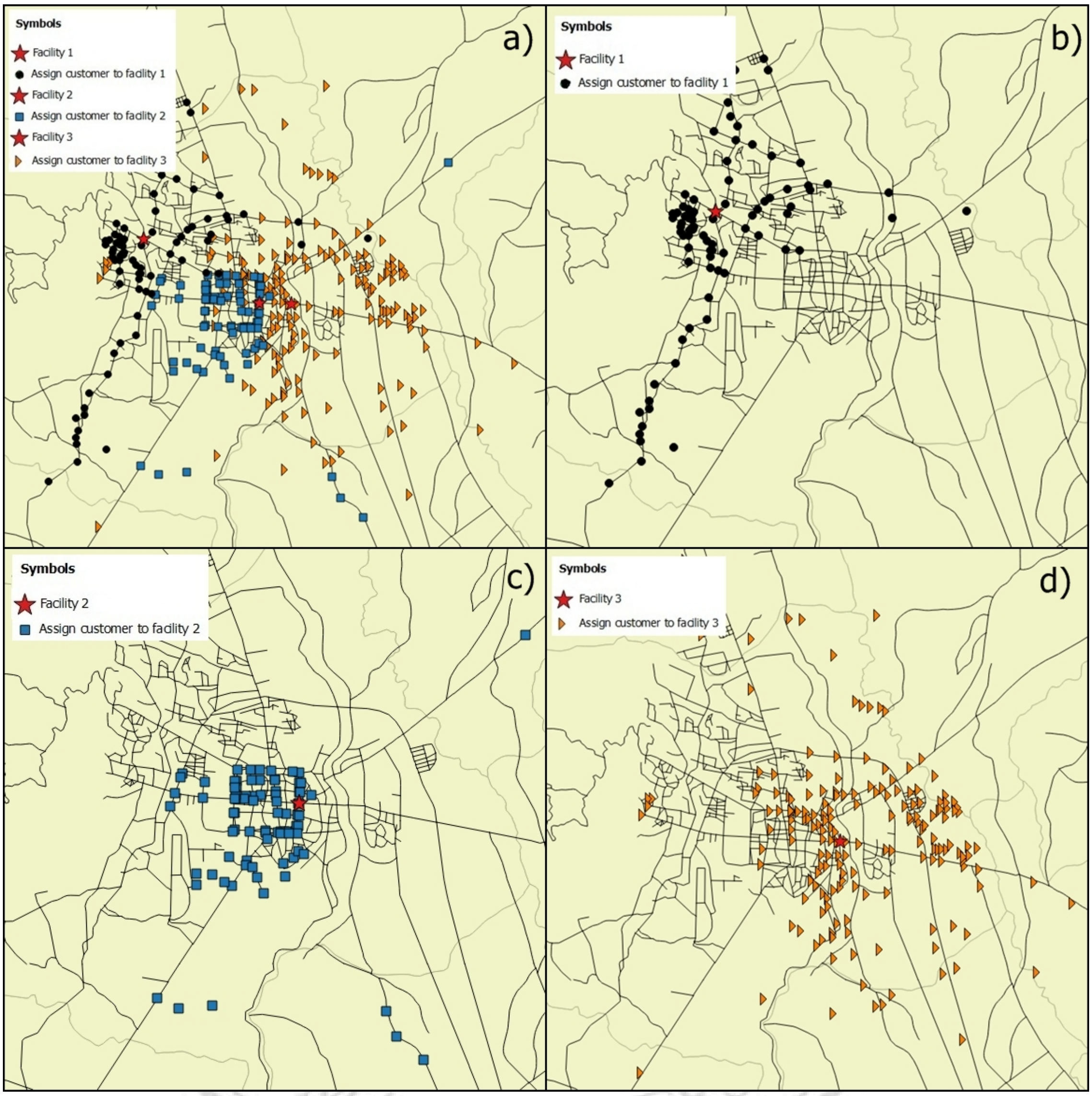

Figure 4.11: The 345 node network optimal solution after size reduction with nodes of degree 1 removed. a) 3 facilities and client groups b) client groups of facility 1 c) client groups of facility 2 d) client groups of facility 3.

Figure 4.12: The 200 node network optimal solution after size reduction with nodes of degree 1 and 2 removed. a) 3 facilities and client groups b) client groups of facility 1 c) client groups of facility 2 d) client groups of facility 3.

Table 4.5: The optimal solution for the municipal waste system in Chiang Mai city.

	Number of opened facility (unit)	Total cost (Baht/year)
Original 432 nodes problem	3	2,065,013.33
Modified 345 nodes problem	3	1,927,064.64
Modified 200 nodes problem	3	1,851,646.51

4.2.2 Cases Studies for Facility Location Problem

The transportation network of Chiang Mai and of 5 other provinces in the Northern part of Thailand is the main focus of the case study. There are 2 aspects involved in each transportation system: 1) municipal waste management and 2) agriculture waste management.

The transportation network in Chiang Mai is the same as the one in Section 4.2.1 with only the 345 nodes of degree greater than or equal to 2 as seen in Figure 4.9. The expense for municipal waste management has been estimated using the same method from Section 4.2.1. The results of the municipal waste management in Chiang Mai using the 3 methods presented in Chapter 3 have been compared with the best results from AIMMS. Figures 4.13 (a), 4.14 (a), 4.15 (a) and 4.16 (a) show the solutions with 3 facilities and their associated client groups obtained from Methods A, B, C, and from AIMMS, respectively. Figures 4.13 (b)-(d), 4.14 (b)-(d), 4.15 (b)-(d), and 4.16 (b)-(d) present each client group and its corresponding opened facility resulting from those methods. The solution details of all methods are shown in Table 4.6. For the agriculture waste management system in Chiang Mai, the biomass energy production from agriculture waste biomass is considered. The related setup costs consist of the construction costs for the 22 megawatts biomass power plant in the present currency with the longer 25-year breakeven point for the biomass power plant instead of 20 years as used in the municipal waste management. The amount of waste is predicted from the average amount of products harvested over a decade from each district that produces the same waste of amount. The transportation costs is calculated in the same way as in municipal waste, that is, estimated from distance, average fuel usage, and fuel price which varies due to the distance traveled to clients. The number of trips have been determined from the round up to the next integer of the waste amount divided by the truck capacity. As shown in Table 4.7, the results of Chiang Mai's agriculture waste management obtained from the 3 methods have been compared with the best results from the AIMMS. Figures 4.17 (a)-(d) show the solutions network with opened facility and their corresponding client groups obtained from Methods A, B, C, and AIMMS, respectively.

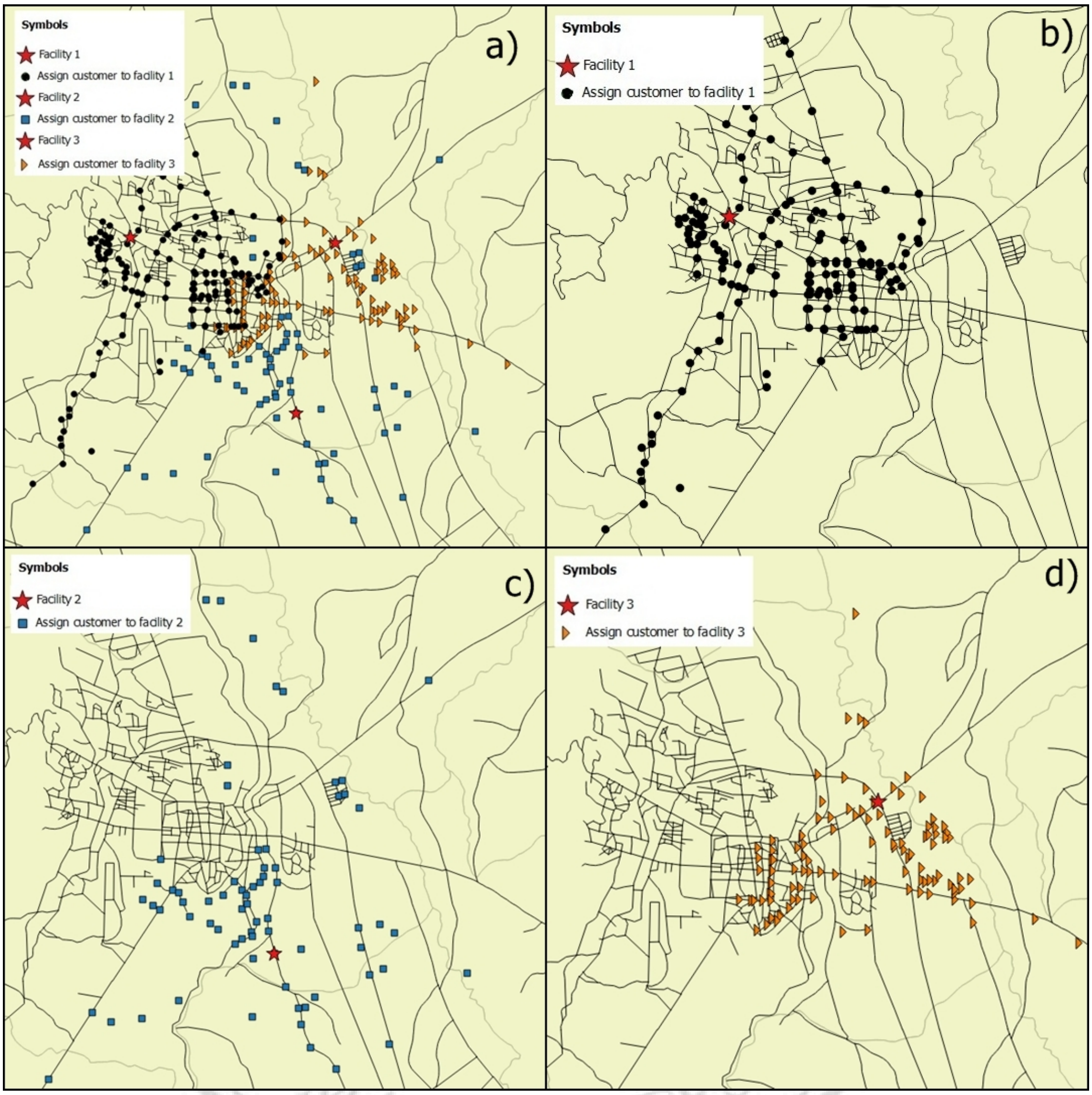

Figure 4.13: The 345 node network solution of municipal waste system in Chiang Mai city obtain from Method A. a) 3 facilities and client groups b) client groups of facility 1 c) client groups of facility 2 d) client groups of facility 3.

Figure 4.14: The 345 node network solution of municipal waste system in Chiang Mai city obtain from Method B. a) 3 facilities and client groups. b) client groups of facility 1. c) client groups of facility 2. d) client groups of facility 3.

Figure 4.15: The 345 node network solution of municipal waste system in Chiang Mai city obtain from Method C. a) 3 facilities and client groups. b) client groups of facility 1. c) client groups of facility 2. d) client groups of facility 3.

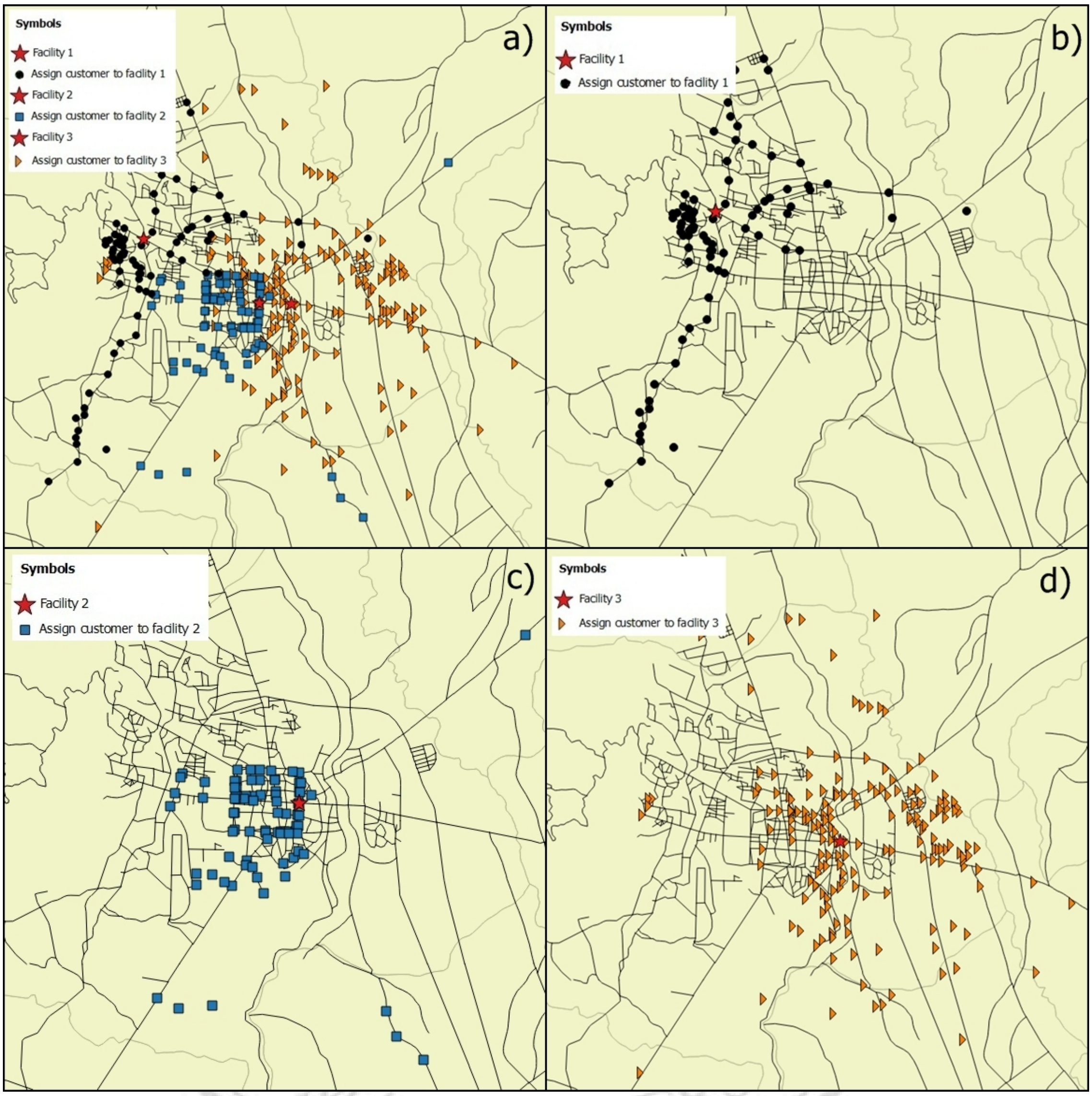

Figure 4.16: The 345 node network solution obtain of municipal waste system in Chiang Mai city from AIMMS. a) 3 facilities and client groups. b) client groups of facility 1. c) client groups of facility 2. d) client groups of facility 3.

Figure 4.17: The 345 node network solution of agricultural waste system in Chiang Mai city. a) network solution obtained from Method A. b) network solution obtained from Method B. c) network solution obtained from Method 3. d) network solution obtained from AIMMS.

Table 4.6: Solution for municipal waste system in Chiang Mai city.

Method	Number of opened facility	Cost(Baht)		
		Setup	Transportation	Total
A	3	1,451,412.60	499,936.08	1,951,348.68
B	3	1,674,706.84	255,061.63	1,929,768.47
C	3	1,563,059.72	484,798.76	1,997,858.48
CPLEX	3	1,451,412.60	475,652.04	1,927,064.64

Table 4.7: Solution for agricultural waste system in Chiang Mai city.

Method	Number of opened facility	Cost(Baht)		
		Setup	Transportation	Total
A	1	52,213,637.76	4,223.30	52,217,861.06
B	1	52,325,284.88	4,091.76	52,329,376.64
C	1	52,325,284.88	4,091.76	52,329,376.64
CPLEX	1	52,213,637.76	4,223.30	52,217,861.06

Another network system applied here is the transportation network in 5 provinces in the Northern part of Thailand: Chiang Mai, Chiang Rai, Mae Hong Son, Lam Poon, and Lam Pang. Both municipal waste and agriculture waste managements as well as the expense calculations related to the matter are similar to those done for Chiang Mai's system. Since the transportation network in 5 provinces in the Northern part of Thailand is too large to illustrate, only solution details are shown in Tables 4.8 and 4.9. This network has 3,211 nodes and, as a result, consists of 10,313,732 variables. When the calculation time is limited at 1,440 hours, this problem cannot be terminated on AIMMS 3.12 using Dell Inspiron 1440 Intel Core 2 Duo T6500 2.10 GHz and 4 GB of RAM.

Table 4.8 compares the results of the municipal waste management in 5 provinces in the Northern part of Thailand from the 3 proposed methods. Shown in Table 4.9, the results using the 3 proposed methods have been compared on the agriculture waste management in 5 provinces in the Northern part of Thailand.

Table 4.8: Solution for municipal waste system in 5 provinces of Northern Thailand.

Method	Number of opened facility	Cost(Baht)		
		Setup	Transportation	Total
A	14	1,116,198.44	48,428,109.90	49,544,308.34
B	28	2,420,065.48	16,875,516.74	19,295,582.22
C	28	2,453,796.77	18,023,361.85	20,477,158.62
CPLEX	unexecuted	unexecuted	unexecuted	unexecuted

Table 4.9: Solution for agricultural waste system in 5 provinces of Northern Thailand.

Method	Number of opened facility	Cost(Baht)		
		Setup	Transportation	Total
A	3	117,171,865.08	32,047,278.36	149,219,143.44
B	3	117,676,537.91	12,519,232.83	130,195,770.74
C	3	117,676,537.91	14,680,779.82	132,357,317.73
CPLEX	unexecuted	unexecuted	unexecuted	unexecuted