



CHAPTER IV

SHUTTLE BUS SYSTEM MODELLING

This chapter describes the development of a model for shuttle bus system. It also describes the development of the computer software that support the operation of the model.

4.1 Modelling Concept

Generally, the main VRP objectives are to minimize the total costs and travelling time and distance. Also, this research tries to solve the problem by minimizing the number of vehicles with time and capacity constraint as total costs control. After, specify the characteristics of the studied problem, and then select appropriated method; in this case, The Saving Algorithm by Clarke and Wright is applied. Finally, develop computer software for making users convenience to change all data or recalculate the result. We can describe procedure to analyse and solve the problem as following.

4.1.1 Characteristics of routing problem

When considering characteristics of routing problem compared with a similar enumeration by Bodin and Golden (1981), who present some broad characteristics in which various VRP may differ, we found that transportation routes from demand point to the company with time constraint, not over working start time, and capacity constraint, not over vehicle capacity can be shown as follows;

- | | |
|-------------------------------------|------------------------------|
| 1. Number of transportation vehicle | Multiple vehicles |
| 2. Type of transportation vehicle | Homogenous (one type) |
| 3. Housing of vehicle | Single depot |
| 4. Nature of demand | Deterministic (known) demand |
| 5. Location of demand | At nodes |

6. Underlying network	Directed
7. Vehicle capacity restrictions	Imposed (all the same)
8. Maximum route times	Imposed (same for all routes)
9. Transportation operation	Mixed (pickup and delivery)
10. Cost	Variable or routing cost
11. Objective	Minimise number of vehicle required

The problem study can be assumed as the single-depot multiple-vehicle node routing problem described a set of routes for a central depot, which services all nodes and minimises vehicle and distance travelled. Solution strategies can be classified as following.

4.1.2 Routing Models

The procedures, which create a solution in a way of each step of the procedure, suitable for the single-depot multiple-vehicle routing problem (sometimes called VRP) provides a set of routes with a central depot by concerning total cost control, distance travelled and time constraint. It means that mathematical model calculation should be followed by two main points of travelling time and total tour distance minimisation.

Mathematical Model

Notation

N	=	Number of demand points
M	=	Number of vehicles
Q	=	Vehicle capacity
$T(L)$	=	Distance for route L
T	=	Total tour distance
C_{ij}	=	Distance from point i to j
D_i	=	Demand at point i

U_i = A vector of positive integer values giving a set of sub-tour elimination constraints in constraint ()

$$X_{ijk} = \begin{cases} 1 & \text{if link } i, j \text{ is concluded in tour } k, \\ 0 & \text{otherwise} \end{cases}$$

The formulation

$$Z_1 = \text{Min } T \quad (\text{a})$$

$$Z_2 = \text{Min } \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} C_{ij} X_{ijk} \quad , k = 1, \dots, M \quad (\text{b})$$

subject to

$$T \geq \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} C_{ij} X_{ijk} \quad , k = 1, \dots, M \quad (\text{c})$$

where

$$\begin{aligned} T(l) &= \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} C_{ij} X_{ijl} \quad , l = 1, \dots, M \\ &= 1 \quad , j = 1, \dots, N + M \quad (\text{d}) \end{aligned}$$

$$\sum_{i=1}^{N+M} \sum_{k=1}^M X_{ijk} = 1 \quad , i = 1, \dots, N + M \quad (\text{e})$$

$$\sum_{i=1}^{N+M} X_{ihk} - \sum_{j=1}^M X_{hjk} = 0 \quad , h = 1, \dots, N+M, k = 1, \dots, M \quad (\text{f})$$

$$\sum_{i=1}^{N+M} \sum_{j=1}^{N+M} D_i X_{ijk} \leq Q \quad , k = 1, \dots, M \quad (\text{g})$$

$$U_i - U_j + (M + N) \sum_{k=1}^M X_{ijk} \leq M + N - 1 \quad , i, j = 1, \dots, N+M, i \neq j \quad (\text{h})$$

In above formulation

- Equation (a) shows the objective function of minimizing the maximal tour.
- Equation (b) shows the objective function of minimizing the total distance.
- Constraint (c) ensures that T represents the maximal tour.
- Constraints (d) and (e) ensure that each point is visited by one and only one vehicle.
- Constraint (f) represents route continuity.

- Constraint (g) implies that the total load of each vehicle does not exceed the vehicle capacity.
- Constraint (h) represents sub tour elimination constraints

4.1.3 Solution Approach

As mention, the complexity of multiple objectives in the mathematical model proposed in the previous chapter. A goal program may be formulated and solved by integer programming code, but the running time is costly and there are some problems of round off error and propagation when the problem is large. This approach is not appropriate in the case of this application.

For a large vehicle routing and scheduling problem (VRP), the most efficient way to obtain the solution is using approximation method (commonly called heuristic). There are several heuristics for VRP deploying different techniques. Most heuristics, however, are the adaptation of some basic well-known procedures for each special scenario. In this research, considering about minimisation of number of vehicles by the way of VRP, this means total time or tour distance of all routes should be minimised saving value of waste time during transportation between demand points. We consider the route with “saving heuristic,” proposed by Clarke and Wright (1964) to maximise the utilisation of all vehicles and to minimise total travelling time with the main reasons follows.

- Practical for large problem analysis
- Near optimal solution, easier to understand and not too complexity
- Able to develop programming with less memory

4.1.4 Proposed algorithm

Clarke and Wright (1964): suggested a simple method for optimum routing of a fleet of trucks of varying capacities used for delivery from a central depot to a large number of delivery points. Clarke and Wright have modified the original method by Dantzig and Ramser. The merchandise is homogeneous with respect to the unit of

capacity. The shortest route between every two points in the system is given. It is desired to allocate loads to trucks in such manner that all the merchandises are assigned and the total distance covered is at minimum. The procedure given is simple but effective in producing a near-optimal solution. The heuristic is called the “saving algorithm” which is “exchange” procedure in the sense that each step one node of tour is exchanged for the better set. First of all, each tour simply connects depot and 1 customer. Then it combines any 2 customers into 1 route if total demand does not exceed vehicle capacity. The saving cost due to combination is calculated and the largest is selected. Then extend the route by combining with each other customer when saving cost due to combine is calculated and the largest is selected, repeating this step until demand exceeds vehicle capacity.

Term of saving value calculation between each 2 points i and j into one route is calculated as:

$$S_{ij} = D_{io} + D_{oj} - D_{ij} \quad (4.1)$$

When S_{ij} is saving value of transportation routing between point i and point j

D_{io} is distance between point i and point O (O is centre point)

D_{oj} is distance between point O and point j

D_{ij} is distance between point i and point j

Therefore, it can show the idea of Clarke-Wright theory as Figure 4.1

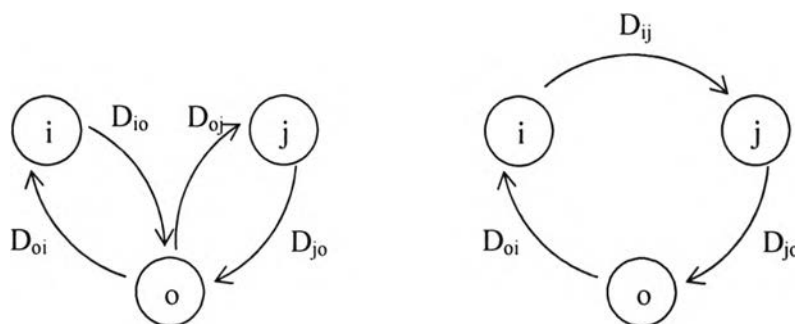


Figure 4.1 Clarke-Wright saving value calculation

From figure above, Dij is saving value of transportation routing which connect between point i and point j because it must return from point i to point o first, then continue to go on again from point o to point j.

4.2 Study of Current System

In order to develop a new model for shuttle bus system, the requirement of current service has to be considered for getting the suitable result for the Company.

4.2.1 Procedure of current system

Procedures to design routes can be explain as in Figure 4.2

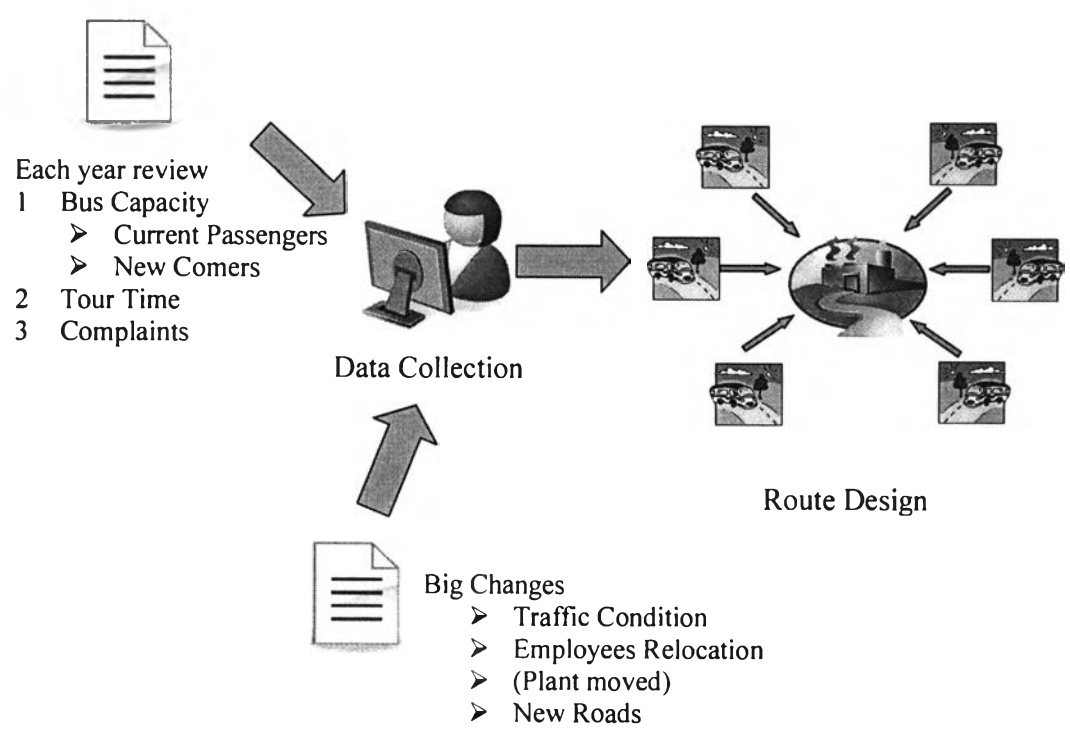


Figure 4.2 Procedures of current shuttle-bus route design

From Figure 4.2, procedures can be explained as follows. In each year, all data of shuttle bus system will be updated, for example; current passengers, travelling time, pick up point, or complaint from users. In addition, if there are large changes resulted to route and time, the shuttle-bus system will be reviewed. The changes may come from traffic condition, employees' relocation or plant moved, or new road constructed. After getting all data, then routes are adjusted with based on previous one (not decide new route).

4.2.2 Current shuttle-bus routes

➤ *Cluster-first route-second procedures*

Cluster demand points, then design routes as a second step. Example and method of this idea were described by Gillet and Miller (1974). Aforementioned, with more than 144 demand points, it can be separated by location (Province/Zone) of each point as follows.

Group A: Bangkok (80 Points)

Group B: Samut Prakarn (65 Points)

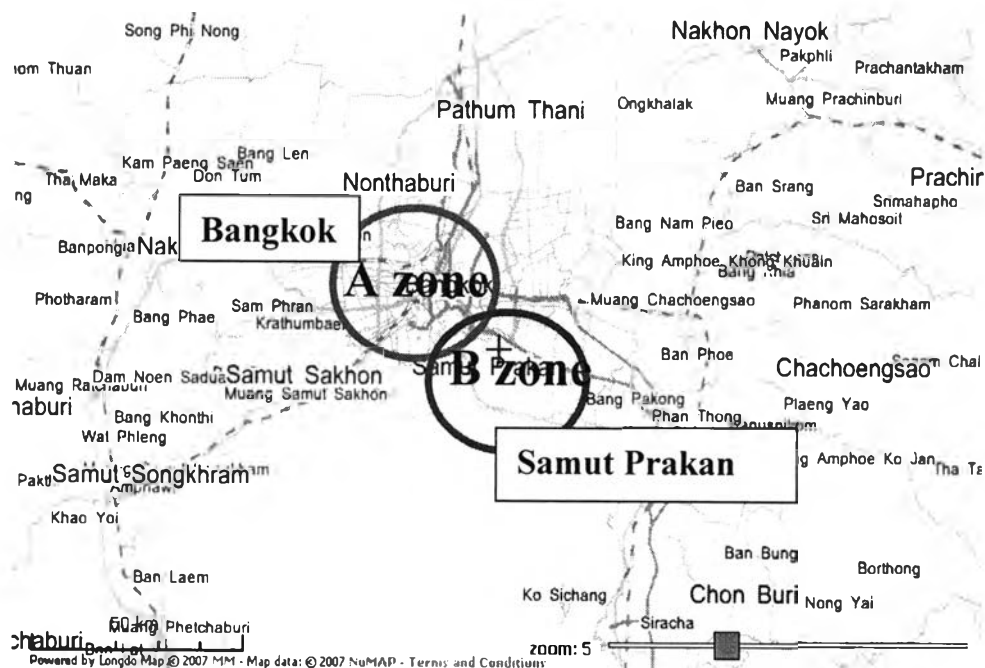


Figure 4.3 Pick up points divided into two zones; Bangkok and Samut Prakarn

➤ *Current shuttle-bus routes in Samut Prakarn*

For scope of this research, focus on Samut Prakarn area only, all routes are shown in Figure 4.4.

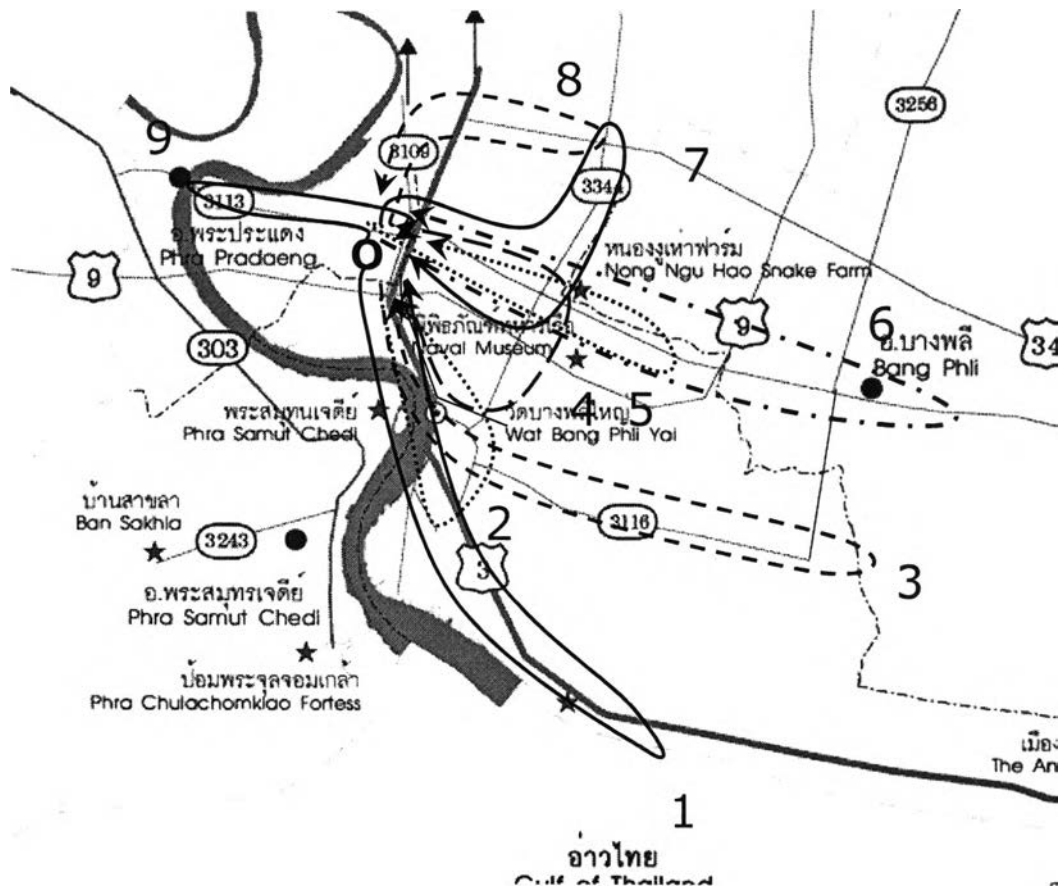


Figure 4.4 Current routes of shuttle bus service

Bus capacity usage of current system can be shown as in Table 4.1.

From Table 4.1, the percentage of total passengers of each route and bus capacity is around 72% that means bus capacity has not been utilised completely

➤ *Each route information*

Table 4.1 Current shuttle-bus route and capacity usage

Route	1	2	3	4	5	6	7	8	9	Total
Passengers	42	30	40	31	34	46	33	39	28	323
Travelled Distance(km)	26.94	18.94	33.72	17.98	22.26	44.94	23.84	20.72	21.74	231.08
Travelled Time (min)	43.34	33.82	57.47	37.65	50.54	106.54	48.66	44.65	43.56	467.23
Capacity Usage (%)	84%	60%	80%	62%	68%	92%	66%	78%	56%	72% (AVG.)

4.3 Data Collection

4.3.1 Distance between each pair of pick up points

Distance measurement between each pair of pick up points is the most difficult and complex because of a large number of 65 pick-up points. This research uses methods by actual measurement and then data generation that is the most accurate and quick.

4.3.2 Bus Capacity

This research uses six-wheel shuttle bus for 50 persons as figure below;



Figure 4.5 Six-wheel shuttle bus with 50 seats being used for picking passengers up

4.3.3 Average Speed

After calculating data for all current routes shown in Table 4.1, this research use average speed for 30 km/h, which can be calculated from;

$$\text{Total distance} / \text{Total time} = \text{Average speed} \quad (4.2)$$

4.3.4 Pick-up Time

Pick-up time per person is 5 seconds, which can be calculated from the average pick-up of each point.

4.3.5 Passengers and Pick-up Points

Table 4.2 Pick up points with number of passengers

Point Number	Point Name	Number of Employees (persons)	Point Number	Point Name	Number of Employees (persons)
1	Toyota	-	34	New Praksa Village	4
2	Phrapradaeng Hospital	15	35	Chamni Soi	2
3	Bangyaprak Temple	7	36	Plengplang Soi	3
4	Klongkud Bridge	3	37	The Metropolitan Power Board Intersection	5
5	Samrongtai Market	9	38	Paolo Hospital	7
6	Isuzu Company	3	39	Samutprakarn Tesco Lotus	7
7	Mahawong Temple	5	40	Kaosaen Village	7
8	Budsaba Village	2	41	Bangpla intersection	5
9	Bunsiri Village	5	42	Bangplee Nakorn Market	3
10	Sarapudchang College	7	43	Krungsiam Village	5
11	Samutprakarn City Hall	3	44	Pornsawang Village	7
12	Paknam Market	11	45	Mungkorn soi	9
13	Taiban Compasses	8	46	Jareonsap Village	5
14	Sailuad Bangkok Bank	5	47	Tepaniwate Village	2
15	Jareonsuk Village	8	48	Namdang Krungsri Ayuthaya Bank	3
16	Ocean Village	4	49	Raewat Village	5
17	Bangpoo Villa	4	50	Tipawan Village	3
18	Sai-ngam Village	6	51	Hino company	1
19	Makefah Village	9	52	Taeparak intersection	3
20	Km.30 Village	2	53	Bangna Intersection	7
21	Pracha Soi	3	55	Baring Soi	5
22	Crocodile Farm	5	56	Imperial Department Store	3
23	Trakob Bridge	1	57	Carrefour Supermarket	1
24	Samutprakarn School	3	58	Bancha Apartment	3
25	Praksa Soi	4	59	Sri-iam Temple	12
26	Satree Samutprakarn School	2	60	Central Department Store	10
27	Petchngam Village	9	61	Lasalle Soi	7
28	Nikom Soi	5	62	Makro Supermarket	3
29	Mungkorn soi	9	63	Baring Soi	3
30	Praksa Village	5	64	Platong Village	1
31	Photasee Soi	2	65	Dansamrong-Temple Soi	5
32	Praksa Temple	2	66	Sritaepa Intersection	3
33	Badipat Village	3		TOTAL	323

4.3.6 Maximum Travelling Time

When considering on start time at the first pick-up point, 90 minutes before working time, 8:00 AM, suits for employees, not too early in the morning. However, time for travelling from the company to the farthest distance is around 30 minutes. Therefore, the proper maximum travelling time is 120 minutes that used in the research.

4.4 Shuttle Bus System Model

After analysing current system and collecting data, a model of shuttle bus service system is developed. As mentioned in “the Solution Approach” in 4.1, The Saving Algorithm by Clarke and Wright is suitable for this problem to get the minimum required buses and travelled distance. When considering the data, travelled distance and time are also the main costs of transportation and the saving value can be calculated from distance and time from each point. The model can be divided into two sections as details of shuttle bus system model and computer program for shuttle bus service.

4.4.1 Details of shuttle bus system model

A. Travelling Distance and Time

With total passengers of 323 persons, 65 demand points in Samut Prakarn can be shown in Figure 4.6 and distance between each point can be shown in Table 4.3.

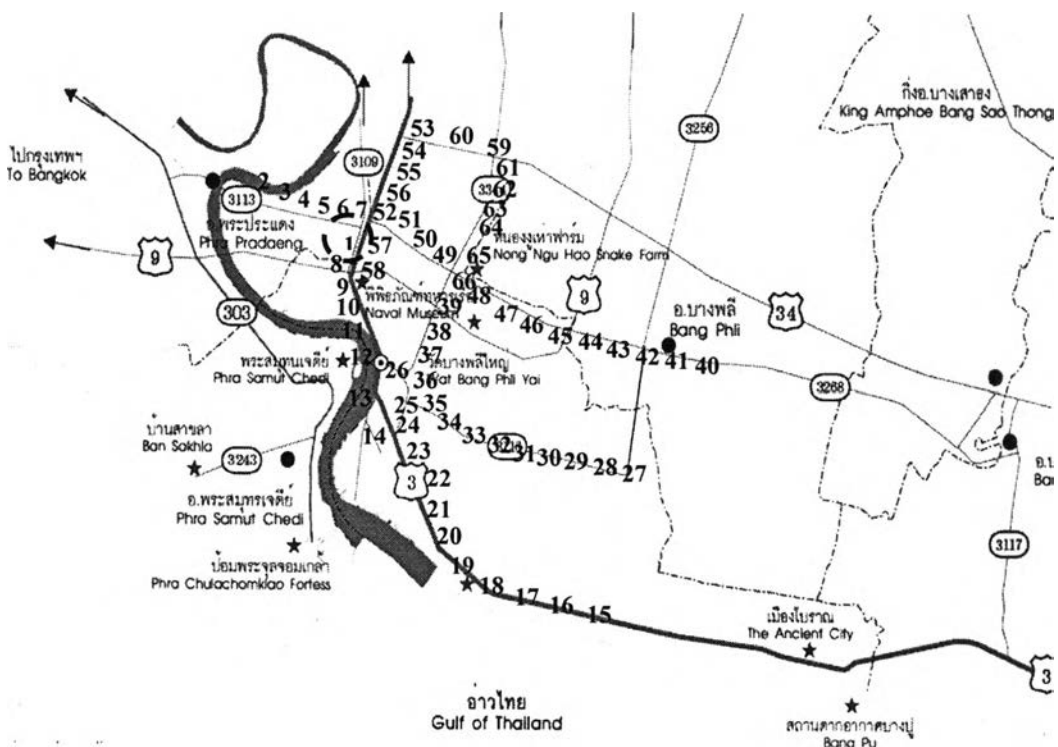


Figure 4.6 Location of all demand points

Table 4.3 Example for distance between each point (unit: km)
(For completed table, see in Appendix A)

Node No.	1	2	3	4	5	6	7	8	9	10
1		8.93	8.43	7.15	5.95	5.10	4.10	1.21	3.21	3.79
2	8.93		0.50	1.78	2.98	3.85	4.85	8.50	10.50	11.06
3	8.43	0.50		1.28	2.48	3.33	4.33	7.98	9.98	10.56
4	7.15	1.78	1.28		1.20	2.05	3.05	6.70	8.70	9.28
5	5.95	2.98	2.48	1.20		0.85	1.85	5.50	7.50	8.08
6	5.10	3.85	3.33	2.05	0.85		1.00	4.65	6.65	7.23
7	4.10	4.85	4.33	3.05	1.85	1.00		3.65	5.65	6.23
8	1.21	8.50	7.98	6.70	5.50	4.65	3.65		2.00	2.58
9	3.21	10.50	9.98	8.70	7.50	6.65	5.65	2.00		0.58
10	3.79	11.06	10.56	9.28	8.08	7.23	6.23	2.58	0.58	

Due to travelling distance can exactly be compared with travelling time which travelling distance can be got from actual distance measuring by data is shown as table 4.3 and demand points location as Figure 4.6. Travelling time between each point calculated by using average speed of 30 km/h from topic 4.1.2 can be shown in Table 4.4.

B. Saving value

From mentioned above, a set of travelling time between each point as Table 4.4 and bring the data of travelling time back to calculate saving value of transportation as Table 4.5 as shown in Figure 4.6 and Equation (4.1).

Table 4.4 Example for travelling time between each point (unit: min.)
(For completed table, see in Appendix B)

Node No.	1	2	3	4	5	6	7	8	9	10
1		17.86	16.86	14.30	11.90	10.20	8.20	2.42	6.42	7.58
2	17.86		1.00	3.56	5.96	7.70	9.70	17.00	21.00	22.12
3	16.86	1.00		2.56	4.96	6.66	8.66	15.96	19.96	21.12
4	14.30	3.56	2.56		2.40	4.10	6.10	13.40	17.40	18.56
5	11.90	5.96	4.96	2.40		1.70	3.70	11.00	15.00	16.16
6	10.20	7.70	6.66	4.10	1.70		2.00	9.30	13.30	14.46
7	8.20	9.70	8.66	6.10	3.70	2.00		7.30	11.30	12.46
8	2.42	17.00	15.96	13.40	11.00	9.30	7.30		4.00	5.16
9	6.42	21.00	19.96	17.40	15.00	13.30	11.30	4.00		1.16
10	7.58	22.12	21.12	18.56	16.16	14.46	12.46	5.16	1.16	

Table 4.5 Example for saving value between each 2-point (unit: min.)
(For completed table, see in Appendix C)

Node No.	1	2	3	4	5	6	7	8	9	10
1										
2			33.72	28.60	23.80	20.36	16.36	3.28	3.28	3.32
3		33.72		28.60	23.80	20.40	16.40	3.32	3.32	3.32
4		28.60	28.60		23.80	20.40	16.40	3.32	3.32	3.32
5		23.80	23.80	23.80		20.40	16.40	3.32	3.32	3.32
6		20.36	20.40	20.40	20.40		16.40	3.32	3.32	3.32
7		16.36	16.40	16.40	16.40	16.40		3.32	3.32	3.32
8		3.28	3.32	3.32	3.32	3.32	3.32		4.84	4.84
9		3.28	3.32	3.32	3.32	3.32	3.32	4.84		12.84
10		3.32	3.32	3.32	3.32	3.32	3.32	4.84	12.84	

C. Process for routes design

Process to select the point to create shuttle bus route can be described as follows.

- a) After getting the saving value of each point, rank the savings $s(i, j)$ and list them in descending order of magnitude. This creates the "savings list." Process the savings list beginning with the topmost entry in the list (the largest $s(i, j)$).
- b) For the savings $s(i, j)$ under consideration, include link (i, j) in a route if no route constraints of travelling capacity and time will be violated through the inclusion of (i, j) in a route, *and* if:

Either, neither i nor j have already been assigned to a route, in which case a new route is initiated including both i and j .

Or, one of the two points (i or j) has already been included in an existing route and that point is not interior to that route, in which case the link (i, j) is added to that same route.

Or, both i and j have already been included in two different existing routes and neither point is interior to its route, in which case the two routes are merged.

- c) If the savings list $s(i, j)$ has not been exhausted, return to Step b, processing the next entry in the list; otherwise, *stop*: the solution to the VRP consists of the routes created during Step b. (Any points that have not been assigned to a route during Step b must each be served by a vehicle route that begins at the depot visits the unassigned point and returns to the depot.)

4.4.2 Computer program for shuttle bus service

From Figure 4.7, procedures of program can be explained as follows;

Process 1 Apply node name and capacity (number of passengers) including load time (time using) as example;

ID	Name	Capacity	Load Time	Unload Time
1	Toyota	0	0.00	0
2	Phrapradaeng Hospital	15	1.25	0
3	Bangyaparak Temple	7	0.58	0
4	Klongkud Bridge	3	0.25	0
5	Samrongtai Market	9	0.75	0
6	Isuzu Company	3	0.25	0
7	MahawongTemple	5	0.42	0
8	Budsaba Village	2	0.17	0
9	Bunsiri Village	5	0.42	0
10	Sarapudchang College	7	0.58	0
11	Samutprakarn City Hall	3	0.25	0
12	Paknam Market	11	0.92	0
13	Taiban Compasses	8	0.67	0
14	Sailuad Bangkok Bank	5	0.42	0

Figure 4.7 Node name, capacity and travelling time

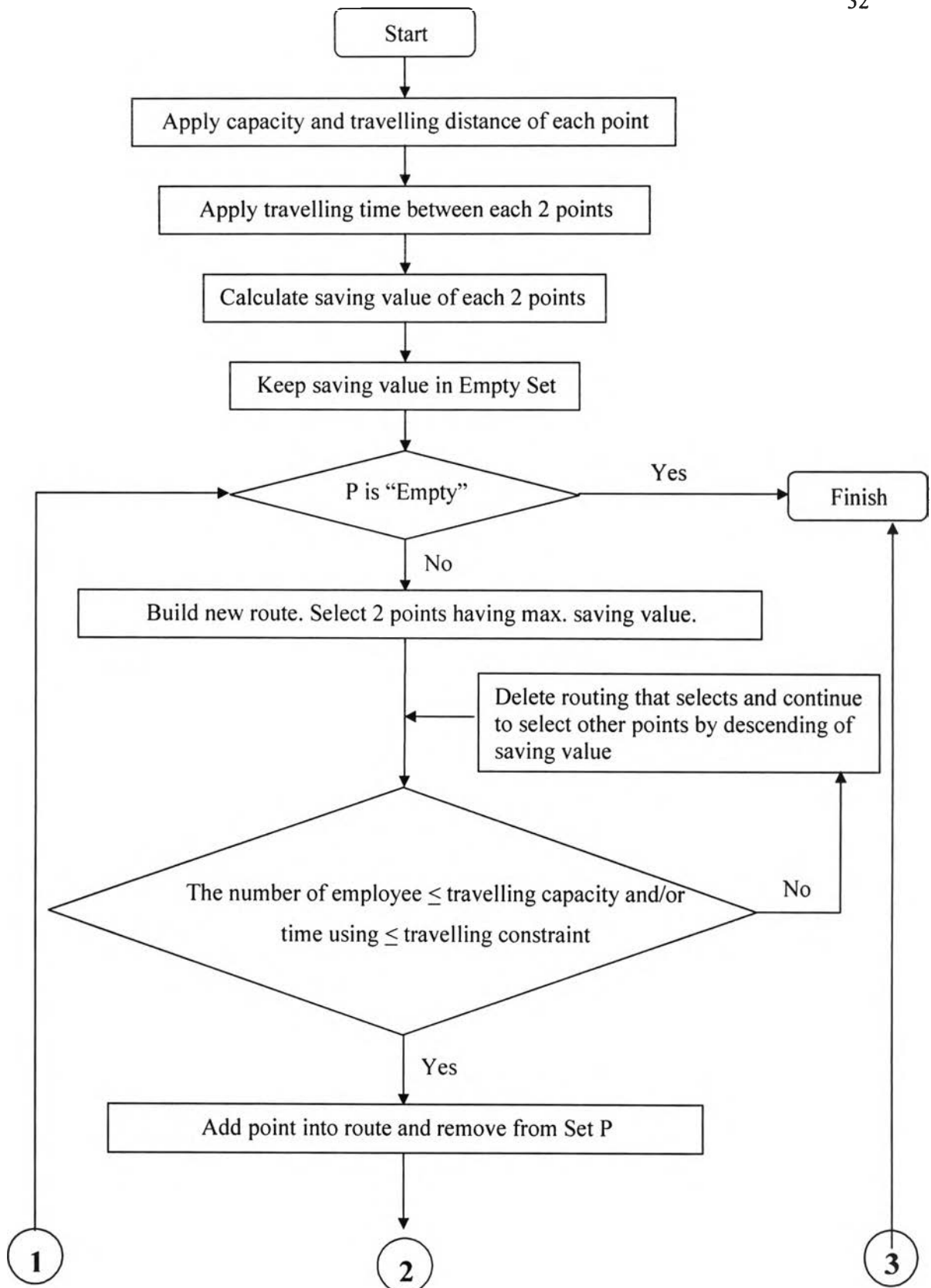


Figure 4.8 Procedures for route selection

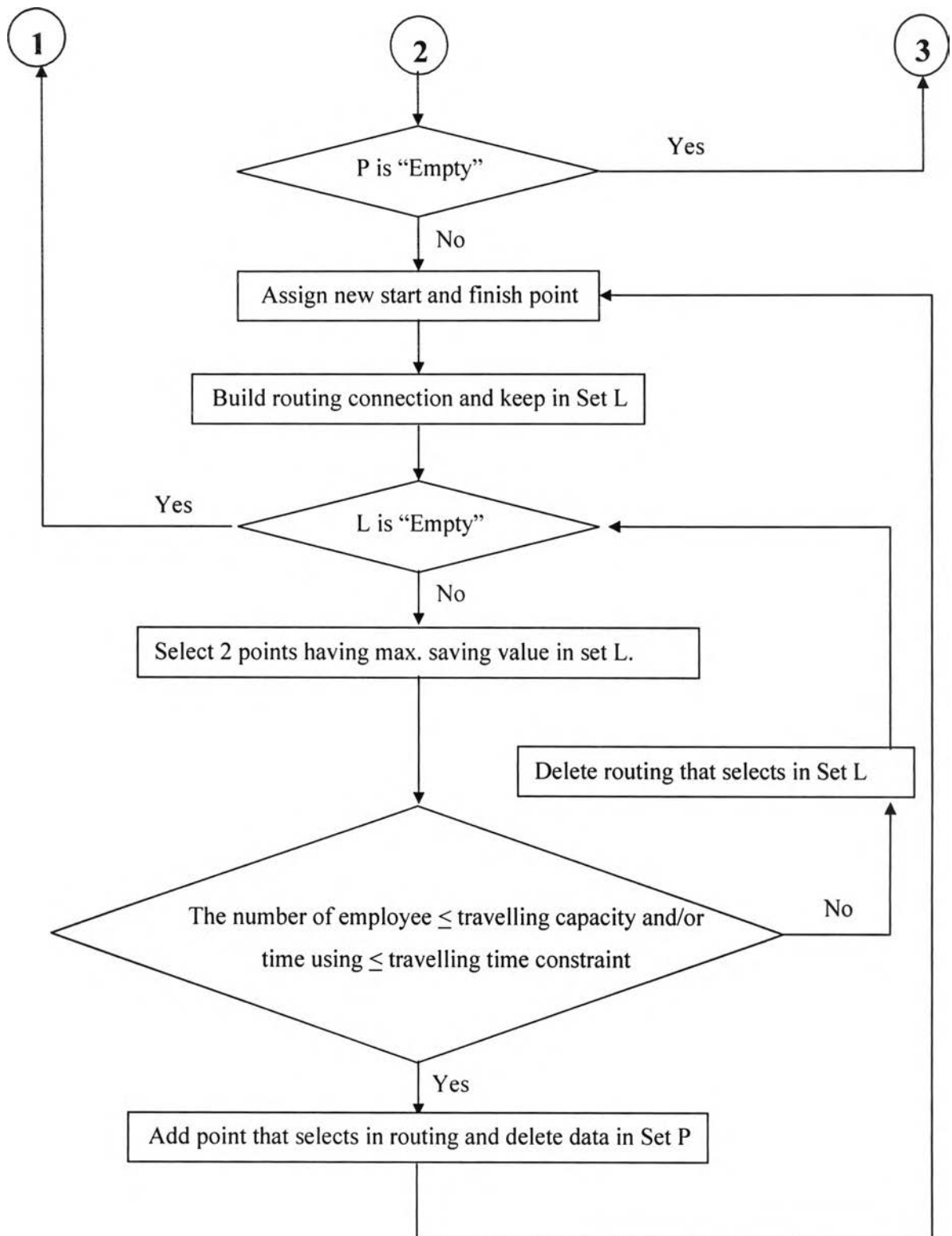


Figure 4.8 Procedures for route selection (cont.)

Process 2 Apply all data of travelling distance between each pair of pick up points (unit in kilometre [km]). For example, travelling distance between point 38 and 47 is 6.76 km. Then, calculate travelling time between each pair of pick up points by using average speed (this case: 30 km/h). For example, travelling time between point 38 and 47 is 13.52 minutes ($6.76 \text{ km} \times 60 \text{ minutes} / 30 \text{ km/h} = 13.52 \text{ minutes}$)

From	To	Distance	Average Speed	Time Use	Saving
38	40	17.24	30	34.48	19.3
38	41	16.46	30	32.92	19.3
38	42	12.96	30	25.92	19.3
38	43	10.34	30	20.68	19.3
38	44	9.76	30	19.52	19.3
38	45	7.76	30	15.52	19.3
38	46	7.46	30	14.92	19.3
38	47	6.76	30	13.52	19.3
38	48	5.37	30	11.94	19.3
38	49	4.12	30	8.24	16.66
38	50	5.93	30	11.86	9.42
38	51	6.07	30	12.14	8.86
38	52	7.67	30	15.34	2.46
38	53	10.25	30	20.5	3.86
38	54	8.95	30	17.9	3.86
38	55	8.55	30	17.1	3.86
38	56	7.46	30	14.92	3.86
38	57	6.19	30	12.38	3.86
38	58	5.63	30	11.26	3.86
38	59	8.18	30	16.36	16.22
38	60	9.76	30	19.52	16.22

Figure 4.9 Travelling time between each point

Process 3 Calculate saving value of each 2-point from formula,

$$S_{ij} = T_{io} + T_{oj} - T_{ij} \quad (20)$$

For example, saving value from transportation between point 38 and 47 find from table 5 [$T_{1,38}$, $T_{47,1}$, $T_{38,47}$]

$$\begin{aligned} S_{38,47} &= T_{1,38} + T_{47,1} - T_{38,47} \\ &= 11.90 + 20.92 - 13.52 \\ &= 19.30 \text{ minutes} \end{aligned}$$

Which saving value result from program as follows,

From Node ID	To Node ID	Distance	Average Speed	Time Use	Saving
38	40	17.24	30	34.48	19.3
38	41	16.46	30	32.92	19.3
38	42	12.96	30	25.92	19.3
38	43	10.34	30	20.68	19.3
38	44	9.76	30	19.52	19.3
38	45	7.76	30	15.52	19.3
38	46	7.46	30	14.92	19.3
38	47	6.76	30	13.52	19.3
38	48	5.97	30	11.94	19.3
38	49	4.12	30	8.24	16.66
38	50	5.93	30	11.86	9.42
38	51	6.07	30	12.14	8.86
38	52	7.67	30	15.34	2.46
38	53	10.25	30	20.5	3.86
38	54	8.95	30	17.9	3.86
38	55	8.55	30	17.1	3.86
38	56	7.46	30	14.92	3.86
38	57	6.19	30	12.38	3.86
38	58	5.63	30	11.26	3.86
38	59	8.18	30	16.36	16.22
38	60	0.06	30	0.06	14.04

Figure 4.10 Saving value results from transportation between each point

Process 4 Keep the saving value in Set P and start to calculate by limitation of travelling capacity and maximum travelling time. In this case, assign constraint of travelling capacity less than or equal 50 employees and travelling time less than or equal 120 minutes as follows,

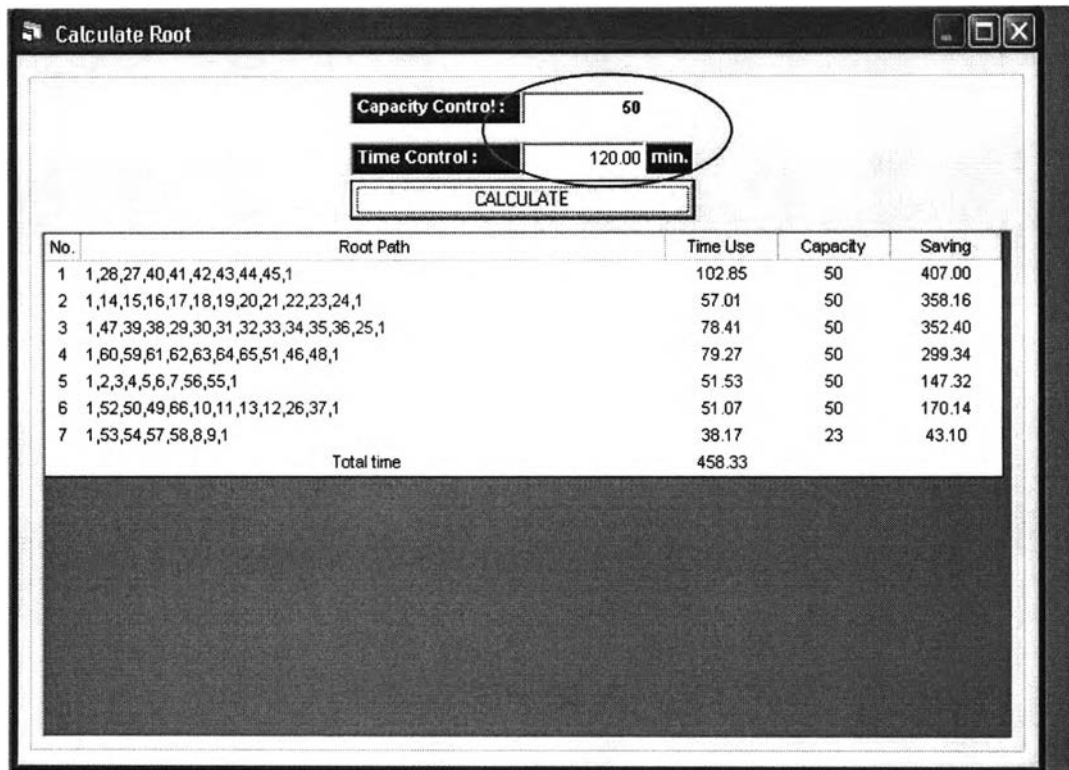


Figure 4.11 Capacity Control and Maximum Travelling Time

Process 5 Check Set P. If it is empty, finish process. But if it is not empty, build a route by Select 2 points having maximum saving value first. If saving value is equal more than 1 point, should select point that has the most number of employees first and if the number of employees is equal also, should select point that make minimization the total travelling time first.

Process 6 Check bus capacity and the total travelling time for selected route since leave from the company and pick employees up go along the route, the result must not over the limitation. If the result is over the limitation, delete this routing in system. Then, continue to select other points by descending of saving value and repeat to check bus capacity and the total travelling time again. If the result is under the limitation, add this point in to the routing and delete data of this point in Set P.

Process 7 Check to confirm the data in Set P again that it is empty or not. If it is empty, finish process. But if it is not empty, build new route, which can be linked with each point. Then, keep the data in Set L.

Process 8 Check Set L that it is empty or not. If it is empty, come back to operate process 5. But if Set L is not empty, build new routing in Set L that has the maximum saving value first. In case of, the maximum value is equal more than 1 point, should select a point that has the most number of employees first and if the number of employees is equal also, should select point that make minimisation the total travelling time first.

Process 9 Check number of employees after picking employees up from every point in selected route, which must not be over bus capacity and total travelling. If one is over the limitation, delete this route in Set L and come back to operate process 8 again. But if both 2 cases are not over the limitation, add this point in routing and delete point in Set P. After that, come back to operate process 7.

Continue to build the route until unable to link point in the route. Then, come back to operate process 5 again.

Repeat process above until all points assigned (Set P is empty).