SCHOOL BUS NETWORK ALGORITHM...BANGKOK CASE STUDY

Mongkut PIANTANAKULCHAI,
Graduate Student
Department of Civil Engineering
Tohoku University
Aoba, Aoba-ku, Sendai,
980-77 Japan
Fax: +81-22-217-7494
E-mail: mongkut@plan.civil.tohoku.ac.jp

Yordphol TANABORIBOON
Associate Professor
School of Civil Engineering,
Asian Institute of Technology
Klongluang, Prathumthanee,
10880 Thailand
Fax: +66-2-223-3333
E-mail: yord@ait.ac.th

abstract: The school bus system in Bangkok was implemented in Bangkok since 1992. However the unacceptable traveling time on school bus was one major of failure of the program. This study intends to overcome this problem. The simulation of school bus routing was carried out in the selected pilot school by utilizing the computer software developed specially for this study. The result shown that the acceptable school bus routes could be generated. It revealed that from the serviceability viewpoint, van is the most suitable for using as school bus in Bangkok while bus is not suitable under assumption of door-to-door service.

1. INTRODUCTION

During last decade, Bangkok, the capital city of Thailand, has been well known for her notorious traffic congestion. Bangkokians have been suffering from traffic congestion caused by substantial growth in population and number of vehicle registered. Traffic jams are becoming to be the way of life in Bangkok, deteriorating the whole economic and quality of citizens' lives.

Traffic problem impacts Bangkokians in wide ranges especially commuters who suffered from traffic jams regularly. Among commuters, school trip makers play important role by the fact that 18.5 percent of all journeys are for education [SPURT 1990]. Moreover, during peak hours, it was stated by JICA (1990) that the number of school trips represented almost one-third of total trips in Bangkok.

The impacts of school trips have been concerned over recent years. Most of people (81.0%) agreed that school trips effect the traffic condition in Bangkok adversely [Jin Fan 1991]. The "School Trip Syndrome", named by Tanaboriboon [1992], elucidated this phenomenon by the use of private autos to send their children to and from school by parents. These resulted to make unnecessary additional trips, contributing as one of major causes of traffic congestion in Bangkok during peak hours. It was recommended that school bus system should be widely introduced in Bangkok to mitigate the problem. Then the school bus promoting program in Bangkok was first established in 1992.

Lacking of information and techniques in planning, operating and management, the government did not operate the school bus. Each school or private agencies are allowed to provide school bus service under regulations. However, not many schools in Bangkok provided school bus. The common reasons are lack of safety and circuitous trips that resulted to the unacceptable and long duration of trips.

This study developed simulation program to overcome such mentioned problems and to achieve the effective school bus system in Bangkok. The objective was to simulate the acceptable school bus routes for 205 students willing to use school bus in selected well known school in Bangkok, Rajini School. The actual data included road network data, users' residence locations, traveling speed, time constraints were collected and utilized in this study. Figure 1 shows the area of simulated school bus routes in this study.

Figure 1. Study Area

2. SURVEY SITE AND DATA COLLECTION

Rajini school, a well known school in Bangkok located on Maharat road, was selected for this study. From total 3,000 students enrolled from kindergarten to high-school level, total 1,080 questionnaires were distributed to parents by cooperation from teacher. From 1080 questionnaires distributed, there were 1034 questionnaires replied. From 510 students willing to use school bus, when rejected some users that did not give enough information for routing (For example, improper information of the location of residence), 205 students were selected for the simulation of school bus routes.

3. SIMULATION OF SCHOOL BUS ROUTING

3.1 School Bus Routing Algorithm

The "*Route first-cluster second*" approach works better than other approaches for the types of problems generally encountered in school bus routing area for fairly densely populated locations. The routing was performed by generated a single tour with the heuristic traveling salesman algorithm and then divided this single tour into feasible subtours. After that all subtours were further improved by other heuristic algorithms. Considered that Rajini school located in fairly densely populated area of Bangkok; serving 205 school bus users in the vicinity of the school, this approach was considered appropriate for using in this study. Figure 2. Show the School Bus Routing Algorithm.

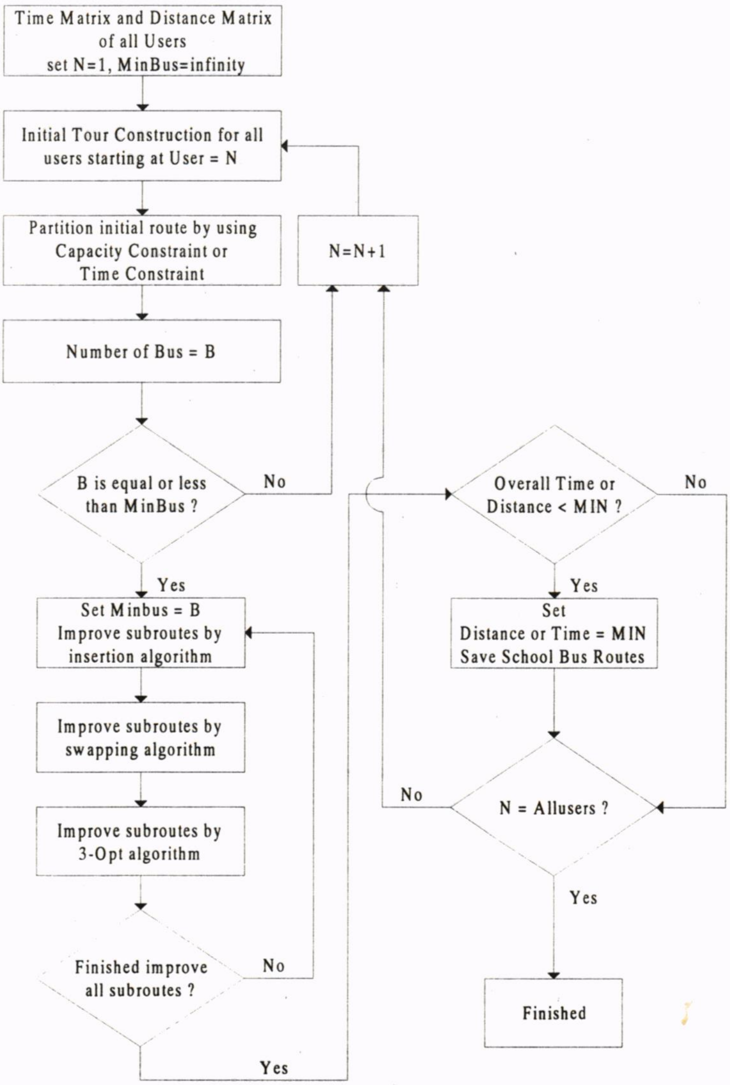


Figure 2. School Bus Routing Algorithm

3.2 Optimization Framework

In this study, the School Bus Routing Problem was considered as Vehicle Routing Problem (VRP). The routing problem can be described as determining for a fleet of buses that serve students, and in what order each bus should visit its customers. The objective of VRP is generally to minimize total traveling distance. However, this study utilized the minimum time path criteria rather than the minimum path criteria for the network because in urban area, usage of minimum time criteria is more reasonable. One reason is that there are many network restrictions such as one-way streets, turn prohibitions, etc. that makes the minimum path criteria not to be realistic. Another reason is that travel time of school bus is the major concern for potential school bus users. In this study, constraints include capacities of the vehicles and time constraint for customers.

The Traveling Salesman Problem (TSP) was applied to solve sub-problem of the VRP. Among the families of heuristic procedures for solving VRP, the "*Composite Procedure*" was selected and it was considered accurate and less expensive in computation time. The composite procedure comprises of 2 heuristic procedures, which are Tour Construction Procedure and Tour Improvement Procedure.

Tour Construction Procedure generated an approximately optimal tour from the input traveling time matrix while Tour Improvement Procedures attempted to find a better tour from given initial tour. Composite procedure constructed a starting tour from the tour construction procedures and then attempted to find a better tour from one or more of tour improvement procedures.

Figure 3 shows school bus routing concept by generating initial single near optimum TSP route and ,partitioning into many subroutes according to time and capacity constraints and then improving these subroutes by tour improvements algorithms.

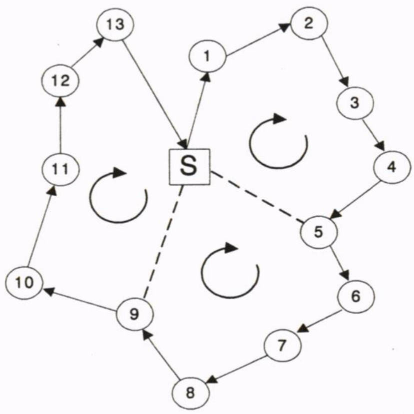
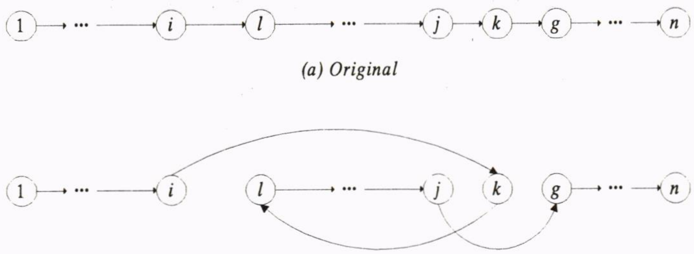


Figure 3 School Bus Routing Concept

In this study, the procedure that generated acceptable result of optimization by within acceptable computation time was considered suitable for school bus routing. From the selection criteria, we selected 1 tour construction procedure and 3 tour improvement procedures to perform composite procedure, which are Nearest Neighbor Algorithm, Insertion Algorithm, Swapping Algorithm and 3-Opt Algorithm respectively.

Nearest Neighbor Algorithm (Rosenkrantz, Sterns and Lewis, 1977) was adopted for school bus routing by selecting one of user nodes to be the first node belonged to the school bus route. Then add the user node that is closest to the last node to the school bus route until every users are selected. The path obtained was used as am initial tour for tour improvement procedures. If we denoted total number of users as n. Every user nodes were selected as the starting nodes, resulting in n initial routes.

Figure 4. illustrates the tour improvement procedure by *Insertion Algorithm* developed in this study. Figure 3(a) shows the initial tour generated by the procedure as mentioned earlier. The first user was represented by node number 1 while the last user was represented by node number n. Other nodes represented any users in the route. The original route could be improved by changing the order of school bus route, trying all possible combinations according to the algorithm presented in Figure 3(b). The algorithm is called an insertion algorithm because the original route, for example 1 , ... , i , l , ... , j , k , g , ... , n, was improved to 1 , ... , i , k , l , ... , j , g , ... , n by inserting user k between user i and user l.

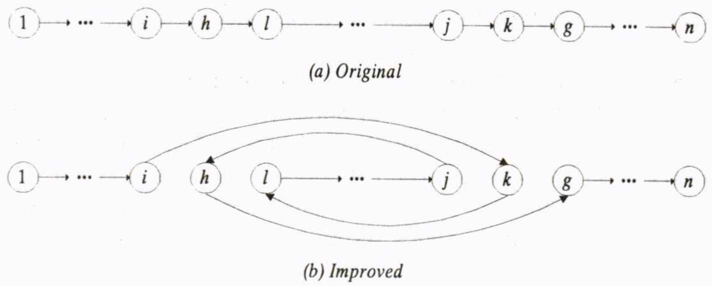


(b) Improved

i	=	1 to n-3
l	=	i+1
j	=	l to n-2
k	=	j+1
g	=	k+1 to n

Figure 4. Tour Improvement Procedure by Insertion Algorithm

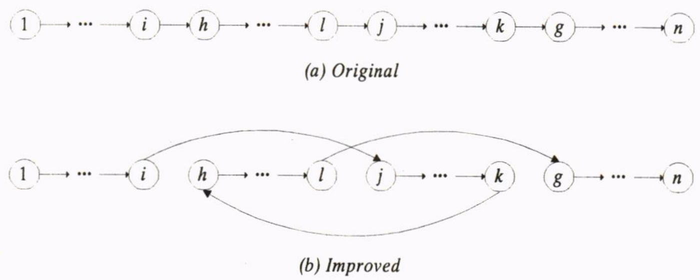
Swapping Algorithm developed in this study are presented in Figure 5. Figure 5(a) illustrates the initial tour using the same concept as Insertion Algorithm. Figure 5(b) shows possible combinations by the algorithm. The algorithm is called swapping algorithm because the original route was improved by swapping the order of user h and user k.



i	=	1 to n-4
h	=	i+1
l	=	h+1
j	=	l to n-2
k	=	j+1
g	=	k+1 to n

Figure 5. Tour Improvement Procedure by Swapping Algorithm

3-Opt Algorithm (Lin, 1965) was adopted in the study. The concept of the algorithm is also presented in Figure 6. In 3-opt algorithm, three segments belonging to the route were reordered. For example, link l-h, l-j and k-g were changed to link l-j, k-h and l-g.



i	=	1 to n-3
h	=	i+1
l	=	h to n-2
j	=	l+1
k	=	j to n-1
g	=	k+1 to n

Figure 6.Tour Improvement Procedure by 3-Opt Algorithm (Lin ,1965)

Composite Procedure was applied to the school bus routing by generated initial routes by Nearest Neighbor Algorithm and then attempted to improve them using tour improvement procedures as mentioned before. The best solution was selected as the optimal school bus route.

3.3 Model Validation

After the school bus routing algorithm was formulated, then the previous case studies were tested and compared to validate that the algorithm could work well. Three case studies with various sizes of problem were selected for validating the algorithm to ensure that the algorithm can work well with all problem sizes. The results of testing are summarized in Table 1. It revealed that the algorithm could work well with various problem sizes and is suitable for this study

Table 1. Model Validation (in unit length)

	Case 1	Case 2	Case 3
Author	John D.C. Little, et al. (1963)	G. Dantzig, et al. (1954)	S. Lin and B.W. Kernighan (1973)
Problem size	Small (6)	Medium (42)	Large (318)
Optimal solution	63	699	41.883
Solution by this algorithm	64	704	44.518
% Different	1.6%	0.7%	6.3%

Figure 7 and Figure 8 show the graphic comparison between the result between optimum solution of 318 cities problem and the solution from this study. The objective is to find the minimum route that passes all 318 cities (points). In each case, the locations of the cities in the X-Y plane are the same but the solutions of optimum routes are different depending on the algorithm used.

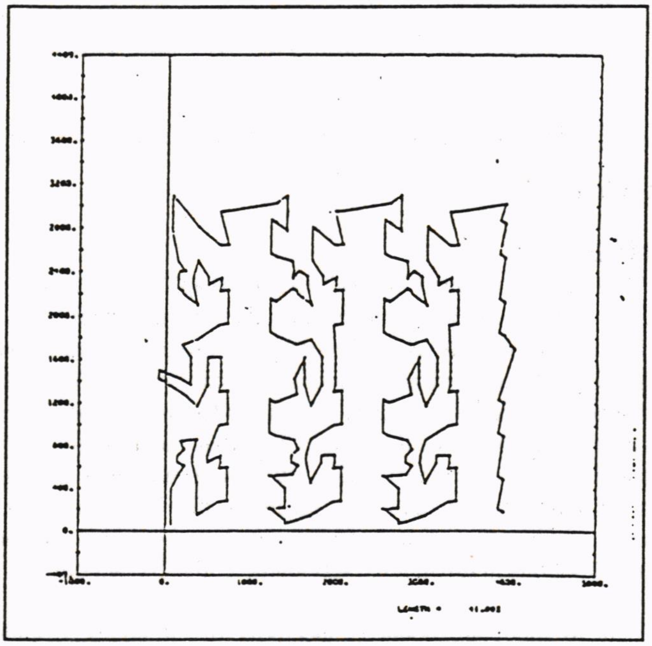


Figure 7. S. Lin and B.W. Kernighan (1973) solution for the 318-city problem
(Source : An Effective Heuristic Algorithm for the Traveling Salesman Problem, Oper. Res., 12, pp. 513.)

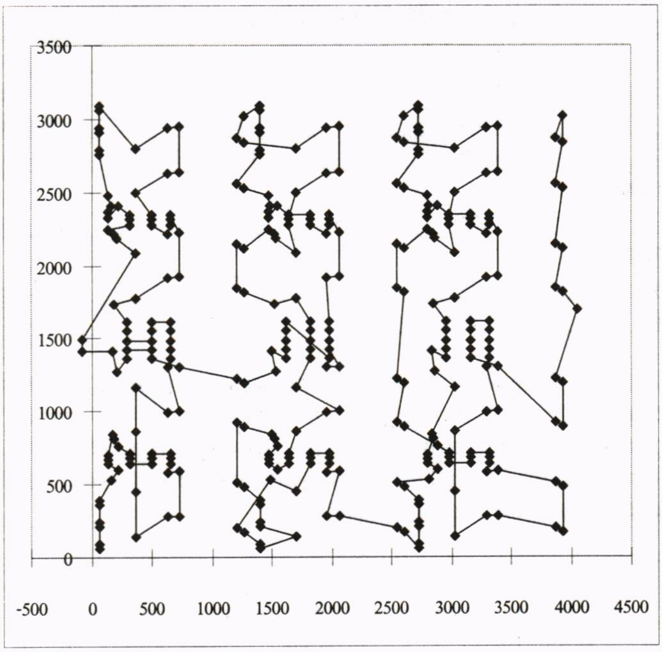


Figure 8. The 318-city solution by algorithm used in this study

3.4 School Bus Routing Data

Road Network Data

Road Network Data can be obtained by road network map. The road network map will give the distance of roads, location of intersections that are important for calculating the travel distance and travel time. By using the computer program, road network data can be coded by assigning all intersections as nodes and road sections as links. In fact, the effective area of school bus service in urban area is limited by the maximum time on bus and bus capacity because the traveling speed in urban area is not so fast and the residences of school bus users are located densely than in rural area. In this study, there were 134 nodes for simulation of road network in the district of the pilot school. The road network covered the area around 10 km. from school that is considered the effective area for school bus in urban area, serving potential 205 school bus users.

The necessary data to input are nodal connectivity of all nodes, distances between adjacent nodes, and average driving speed of that link (if known or assumed). Other network constraints can be included such as one-way streets, turn prohibition or turn penalty time at the intersection. After all data were entered, the data were stored in files and then calculating the minimum path and distances using dynamic programming concepts.

School Bus User Data

The user data can be obtained from questionnaires. The location of user's residences and school were coded together in the base map as user nodes. The location of user's residence was coded using road network node as a reference. The minimum time and distance between user nodes then can be determined by combining the road network base data and user data together. In this study, 205 users were used in simulation of school bus routes.

Bus Capacity

The bus capacity is one of constrains in routing problem. In this study, 3 types of buses were selected for simulation, which are Van (12 passengers), Micro Bus (20 passengers) and Bus (40 passengers20 passengers) and Bus (40 passengers)

Traveling Speed

Although, an assumed travel speed along the main and minor streets is used in this study to simulate the bus routing, the actual traveling speed along main roads of school bus route was estimated by using travel speed study. The travel speed study was conducted by using the test car to move along with the traffic stream and calculate the average journey speed. Since the school bus may operate both in the morning and afternoon. The travel speed study was conducted both in the morning and in the afternoon to estimate the traveling speeds that are supposed to be different during the day.

The study first assumed speed for initial routing calculation and then selected a resulted school bus route to check with the assumed traveling speed . After the speed surveys were carried out, it was considered to use average journey speed of 20 km/hr as a base case for further analysis.

Traveling Time

Travel time of the journey can be determined from the relationship between distance and average traveling speed along school bus routes, including all average delays from intersections and other points. Travel time also included dwelling time for loading and unloading the passengers. In this study the average value of 0.5 minutes was used.

Time Constraints

Time constraints were included in the analysis. The main reason is that parents do not like their children to be in the school bus for a long time. For this reason, the opinion regarding the maximum allowable time in the school bus was obtained from the questionnaires and then was selected for the analysis. Nonetheless, this study also employed time constraints to simulate the school bus routes with 4 alternatives proposed. The simulated cases were 1) No Time Constraints 2) Maximum Time on Bus 60 minutes 3) Maximum Time on Bus 90 minutes and 4) Maximum Time on Bus 120 minutes.

3.5 School Bus Routing by Computer

After all necessary data for school bus routing were prepared then the school bus routing can be done by using computer software for routing school bus in the morning and afternoon respectively. The program used routing procedure as described by considering all constraints. The school bus routing procedure can be summarized as illustrated in Figure 9.

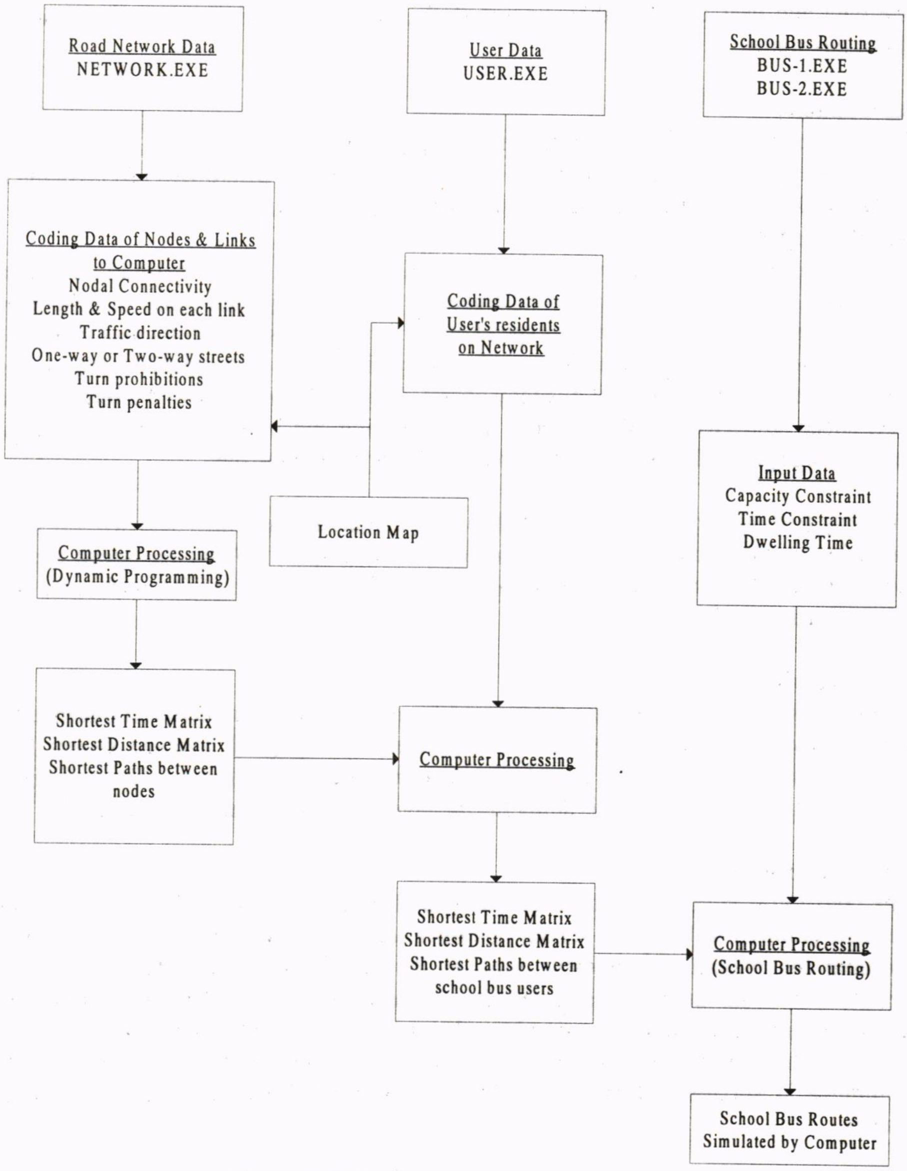


Figure 9. School Bus Routing Procedure

3.6 Result of School Bus Routes

After running the school bus routing software, the result of school bus routes were printed out into output files. The example output of school bus routes is shown in Figure 10, which was excerpted from actual result of school bus routing.

BUS NO. 1 ROUTE	DWELL TIME (MIN)	RUNNING TIME (MIN)	TIME ON BUS (MIN)	BUS DISTANCE (KM)
0 =>51	0	4.54	0	2.27
51 =>111	0.5	1.42	1.92	2.98
111=>107	0.5	0.6	3.02	3.28
107=>99	0.5	0.82	4.34	3.69
99 =>36	0.5	1.3	6.14	4.34
36 =>80	0.5	2.28	8.92	5.48
80 =>90	0.5	2.06	11.48	6.51
90 =>205	0.5	0.62	12.6	6.82
205=>98	0.5	0.36	13.46	7
98 =>170	0.5	1.44	15.4	7.72
170=>49	0.5	0.1	16	7.77
49 =>55	0.5	6.08	22.58	10.81
55 =>0	0.5	3.18	26.26	12.4
NUMBER OF USERS	=	12		
RUNNING TIME (MIN)	=	30.8		
MAX TIME ON BUS (MIN)	=	26.26		
DISTANCE (KM)	=	12.4		

BUS NO. 2 ROUTE	DWELL TIME (MIN)	RUNNING TIME (MIN)	TIME ON BUS (MIN)	BUS DISTANCE (KM)
0 =>163	0	5.4	0	2.7
163=>52	0.5	3.06	3.56	4.23
52 =>154	0.5	0	4.06	4.23
154=>4	0.5	0.3	4.86	4.38
4 =>109	0.5	0.8	6.16	4.78
109=>131	0.5	2.6	9.26	6.08
131=>84	0.5	1.1	10.86	6.63
84 =>201	0.5	0.52	11.88	6.89
201=>147	0.5	0.88	13.26	7.33
147=>93	0.5	2.72	16.48	8.69
93 =>22	0.5	1.9	18.88	9.64
22 =>44	0.5	3.08	22.46	11.18
44 =>0	0.5	11.66	34.62	17.01
NUMBER OF USERS	=	12		
RUNNING TIME (MIN)	=	40.02		
MAX TIME ON BUS (MIN)	=	34.62		
DISTANCE (KM)	=	17.01		
*	*	*		
*	*	*		
*	*	*		
TOTAL USERS	=	205		
USE ALL BUSES	=	18		
TOTAL TIME (MIN)	=	839.82		
TOTAL DIST (KM)	=	469.43		
BUS CAPACITY	=	12		
MAX TIME ON BUS (MIN)	=	NO TIME LIMITATION		
DWELL TIME / USER (MIN)	=	0.5		

Figure 10. Example of Result of School Bus Routing by Computer

Figure 10 illustrates the school bus routes in the morning for Van (capacity 12) with no time limitations using average speed 20 km/hr. Numbers in school bus routes represented the user's name or ID number which are input in user data file. Number zero represented the school node. All types of school bus with various time limitations were simulated and the results were summarized in next section.

3.7 Speed and Vehicle Types

In order to investigate natural characteristics of vehicle in each type, the time limitation was not yet considered in these cases. Then the average distances and maximum time on bus of school bus routes in any cases were calculated from the criteria that the Load Factor of school bus must not be less than 0.8. For example, Van with 12-seat capacity should serve at least 10 passengers per vehicle. Those vans that have number of passengers less than 10 were considered to be infeasible and were rejected. In the same way, the minimum passengers considered for Microbus (20) and Bus (40) were 16 and 32 respectively. Table 2 and Table 3 show the summary of results.

Table 2. Average Maximum Time on Bus (minutes) varied by Speeds

Speed (km/hr)	Van (min.)	Microbus (min.)	Bus (min.)
10	131.0	198.7	337.2
20	68.8	103.9	177.4
30	47.4	72.6	123.1

Table 3. Average Distance of School Bus (km/trip) by Bus Types

Van	Microbus	Bus
26.2	36.8	58.5

3.8 Evaluation of School Bus Routing Performance by Serviceability Index

To evaluate the performance of school bus routing in real world cases, the average speed 20 km/hr was selected in the analysis by varying the vehicle size and time limitation on bus. The serviceability index (%) was used to evaluate the routing performance by using the same criteria that the Load Factor of vehicle must not be lower than 0.8 under constraints. Then the serviceability index is denoted by the percentage of school bus users successfully served by the total potential users. Table 4 shows the summary of results. It is noted that the maximum time on bus shown are the average values of the maximum traveling time of each school bus in the school bus fleet according to each school bus type.

Table 4. Serviceability of School Bus (%) by Bus Type and Maximum Time on Bus

Bus Type	Maximum Time on Bus (min)			
	-	120	90	60
Van	100	96.1	80.7	59.6
Microbus	100	81.5	71.8	17
Bus	100	9	0	0

In serviceability analysis, when varied maximum time limitations on bus and bus sizes, the results showed that lower bus capacity can produce more serviceability. When varied maximum time on bus from 120, 90 and 60 minutes, the percent of successfully served all passengers decreased. The average serviceability of Van(12) was 96.1, 80.7 and 59.6 percent while Microbus(20) could serve 81.5, 71.8 and 18 percent of total users, respectively. It is also obvious that Bus(40) is not applicable when applying time constraints. Furthermore, it was found that when the time constraint is lower, the speed had much effect on the serviceability. For example of Van(12) with 60 minutes time constraint, if the speed vary by from 30 to 20 and 10 km/hr, the simulation shown that the serviceability would drastically drop from 86% to 57% and 6%, respectively.

4. CONCLUSION

From the results of simulation, it could be concluded that regardless of time limitations, the average trip distance of Van(12), Microbus(20), and Bus(40) were around 26, 37 and 59 km/trip respectively, nearly the same for both morning and afternoon period. Varying average speeds from 10 to 30 km/hr, for example of Van(12), the average maximum time on bus varied at wide range from 47 minutes to 2 hours. .If assumed the speed of 20 km/hr as the average speed of buses, then the average maximum time on bus of Van (12), Microbus(20), Bus(40) were around 69, 104 and 174 minutes, respectively. It was noted that the average maximum time on bus in the morning and afternoon are almost the same because of assumption of the same speed. In reality, the afternoon trips will consume longer travel time than that of the morning due to slower traveling speeds obtained from the speed survey.

In this study, the maximum time limit on bus was considered as a strong constraint. The user that experiences maximum time limit is the person who lives the farthest away from school. For other users, time spending on the bus usually vary by the distance from school. However, when considered the average time on bus, Generally, from the result of school bus routes simulation, the average time on bus were approximately around 0.5 times of the maximum allowable time on bus. For example, cases of maximum 120, 90, 60 minutes allowable time on bus revealed the average time on bus approximately 60, 45 and 30 minutes, respectively.

From the serviceability viewpoint, van is the most suitable for using as school bus in Bangkok while bus is not suitable under assumption of door-to-door service. When time limit is not too low, microbus would produce serviceability about 10% less than that of van.

From this study, traveling speed had much affect for school bus performance. To improve the school bus system, the school buses should have priority to use transit lanes, for example, bus lanes, to increase their performance and to attract more people to use them. The cooperation in school bus routing for the schools in the same district could improve the efficiency of school bus routing because more school bus users would result in the reduction of maximum time on school bus.

It seems that using mixed sizes of school bus will produce better service and serviceability index could be improved. But it is needed to formulate a new school bus algorithm which is beyond the scope of this study. As mentioned earlier, this study rejected any buses when load factor is below 0.8, but in case of mixed vehicle sizes, the rejected users should be reassigned to the bus of lower capacity. The better improvement may consider aggregate those rejected users and perform routing again by using smaller bus sizes.

The main objective of this paper is to overcome the unacceptable traveling time of running school bus by applying a school bus algorithm to the real world data. Another one factor that is necessary to consider when operating school bus is the cost factor. However, to discuss for a financial problem of a school bus system may go beyond the scope of this paper. Piantanakulchai (1996) investigated the cost factor of operating school bus by adopting the result of school bus routes from this simulation to the financial analysis. It was concluded that the fare rate for school bus is too high for average income people. If the government would like to serve the majority of the society, subsidy is recommended as an attractive measure for people to use the school bus system.

Another measure that could support school bus system is the stagger school hours. It would result in substantial reduction of school buses needed because school buses could serve for another school due to stagger school times. Consequently, it would substantially improve the financial performance and would result in the lower fare rate.

REFERENCES

JICA (1990), The Study on Medium to Long Term Improvement/Management Plan of Road and Road Transport in Bangkok in the Kingdom of Thailand, **Medium to Long Term Road Improvement Plan Main Report**.

Jin Fan (1991), The Impact Of School Trips In Bangkok, **AIT Thesis**, GT-90-8, Bangkok,Thailand.

Lin, S. (1965), Computer Solutions of the Traveling-Salesman Problem, **BSTJ 44**, 2245-2269.

Piantanakulchai, M.(1996), School Bus System in Bangkok, **AIT Thesis**, Bangkok, Thailand.

Rosenkrantz D., Sterns R. and Lewis P. (1977), An analysis of several heuristics for the traveling salesman problem, **SIAM J. Comp. 6**, 563-581.

SPURT(1990), "School Traffic", **Working Paper No.12**, Seventh Plan Urban and Regional Transport, Office of The National Economic and Social Development Board, Thailand.