Route Optimization of Feeder Bus for Electric Train Service

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Abstract— **The Electric Train Service (ETS), which connects the cities of Kuala Lumpur and Ipoh, has been in operation since 2010. The ETS has not only provided a safe, fast and cost effective way to travel between these two cities, but has also spurred the economic activities of the major towns between them. However, the lack of an effective feeder bus system that brings commuters to the ETS stations remains a significant problem. The objective of this paper is to design a wide coverage feeder bus route that is also effective and efficient in terms of service. Specifically, genetic algorithm has been used to optimize the feeder bus route. The optimization is performed to attain the widest service coverage, lowest operation cost, shortest total travel time, shortest total travel distance and to meet the highest demand. As a test case, the Batu Gajah, Perak ETS station has been used. Simulation results show that solving the route optimization problem can produce a wide coverage route with high effectiveness and efficiency in service.**

Keywords – Route Optimization, Genetic Algorithm

I. INTRODUCTION

Malaysia introduced the Electric Train Service (ETS) in the year 2010. The ETS operates between the major cities of Kuala Lumpur and Ipoh. In between these two cities are 14 stops at major towns such as Kepong, Rawang, Kampar, Batu Gajah and others. The ETS has provided a safe, fast and cost effective way to travel between these two cities and has been well received by the commuters. Furthermore, it has also spurred the economic activities of the major towns between them.

Currently, there are a total of 5 KTM Class 91 train sets with 6 cars each [1]. The ETS can operate up to a maximum speed of 140 km/h. Each of the train can carry up to 350 passengers. There are two main classes for ETS train: the Silver service and Gold service. The Silver service trains take 2 hours and 30 minutes between KL Sentral and Ipoh and stops at 14 stations. On the other hand, the Gold service trains take 2 hours and 20 minutes with only 8 stations stops. The Silver service and Gold service fares are RM25 and RM35 respectively, for a one way trip [2].

Although the ETS is a reliable and efficient form of transportation, there is still the problem of getting to and from the station. Parking may be limited at some stations while security is also a concern in view of the high number of vehicle thefts. On the other hand, a taxi ride may set one back by the same amount as the ETS fare itself. Clearly, an efficient and effective feeder bus system (FBS) can be a viable and welcomed solution to the commuters. At the moment, such a FBS is not available to complement the ETS.

Nevertheless, the success of the FBS itself depends critically on the route that it takes. The feeder bus route will determine the service coverage, travel time and cost which in turn determine the fare charged. For the feeder bus operator, the profit, which is derived from revenue minus costs, is of main concern. Besides that, many public bus systems have small area of service coverage and also lack efficiency. Some of them have high operation cost, long travel time, long travel distance, long access time and low number of passengers. Hence, it is important to optimize the feeder bus route connecting to the ETS station to provide the best service for the public in terms of service coverage, cost and time.

In this paper, the modeling and optimization of the feeder bus route that connects to the ETS station has been undertaken. Specifically, genetic algorithm has been used to optimize the feeder bus route. The optimization is performed to attain the widest service coverage, lowest operation cost, shortest total travel time, shortest total travel distance and to meet the highest demand. As a test case, the Batu Gajah, Perak ETS station has been used. Nevertheless, the algorithm can be employed for other types of public bus transportation systems.

The rest of the paper is structured as follows. In Section II, a short review of the relevant route optimization models from the literature will be given. The description of the genetic algorithm employed in the route optimization is described in Section III. Section IV shows the simulation results. Finally, Section V concludes the paper.

II. REVIEW OF ROUTE OPTIMIZATION MODELS

Several works have been carried out in route optimization. A model to optimize feeder routes and coordinated schedules of feeder bus in Dublin, Ireland is proposed in [3]. In this model, the feeder routes and schedule coordination for feeder bus are done through 2 phases by using the routing sub model and scheduling sub model. The advantage of this model is that it considers many objective functions such as travel time, waiting time and total bus travel distance. However, the disadvantage of this model is that it takes more steps and longer time to develop the feeder routes and

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coordinated schedules for feeder buses in 2 stages using routing and scheduling sub models. Besides that, this model only used k-shortest paths to generate the feasible routes during the development of feeder routes. This shows that there is a lack of service coverage that leads to a lower passengers' access time to transit network and lower demand. The model was improved by the same authors in [4] by using only Genetic Algorithm (GA) to develop both feeder routes and frequencies leading to schedule coordination of feeder buses with main transit at the same time. The advantage of the model is the improvement of overall load factors.

The authors in [5] used Deoxyribonucleic Acid (DNA) algorithm on bus route optimization by analyzing both the shortest distance by bus and the minimum interchange. However, it only solved the optimization of transfer time and transfer number of buses, but did not consider the problem of the ridership.

On the other hand, an improved Ant Colony Algorithm was proposed in [6] to optimize the route for bus dispatching by considering both multi-objective functions and constraints. The advantages of this model are the improved of load factor, reduced of passenger average latency and increased in number of reasonable routes. However, the disadvantage of this model is its high complexity.

Ciaffi, Cipriani and Petrelli developed a procedure that simultaneously generates routes and frequencies of the feeder bus network in a real size large urban area [7]. The model consists of 2 phases, the first phase uses heuristic algorithm that include k-shortest path algorithm and Travelling Salesman Problem algorithm (TSP) to generate feasible routes. The second phase uses Genetic Algorithm (GA) to find the optimal feeder bus routes and their frequencies. The main advantage of this model is that it considers more objective functions such as the in-vehicle travel time, access time, waiting time, transfer penalty, total bus travel distance and total bus travel time when compared to other models.

It is important to note that the feeder bus route optimization problem considered in this paper is different from the famous travelling salesman problem (TSP) [8]. Firstly, in TSP, every station needs to be visited, whereas here the maximum number of station is defined but the route can consist of less number of stations. Secondly, in TSP, only the distance is considered between stations whereas more realistic parameters such as number of passengers, fare, petrol cost and many others can be included. Last but not least, the proposed modeling can be extended to include interdependent parameters, e.g. where different fares may affect the number of passengers. Clearly, considering such practical factors will result in a realistic but much more complex model. For such a complex model, heuristic algorithms are known to be more suitable.

III. FEEDER BUS ROUTE OPTIMIZATION USING GENETIC ALGORITHM

The Batu Gajah, Perak ETS station has been used as a test case due to its proximity to our university. Nevertheless the algorithm can be used for other stations or even other types of public bus transportation systems. The first step is to identify all the hotspots within the radius of 20km from the Batu Gajah ETS Station by doing a survey based on the population and activity of each hotspot. A hotspot is defined as an area where there are a considerable number of commuters. The second step is to determine the shortest path between all the hotspots. Finally, the third step is to employ the GA to obtain the optimized feeder bus route.

A. Hotspots around Batu Gajah ETS Station

Batu Gajah is a town in the state of Perak with a population of about 34000 people. The Batu Gajah ETS station is set as the starting point and ending point of the bus route. There is a hospital, a bus and taxi station nearby Batu Gajah Old Town as shown in Fig.1. These are the places that are always crowded with people. Tronoh is a small tin-mining town situated in between the Ipoh-Lumut highway. There is a bus station in the town of Tronoh with buses to Ipoh. Universiti Teknologi Petronas (UTP), which is located near to Tronoh, currently has about 7000 students. Taman Maju Bus Station, which is further up the highway, caters to both intra and inter-state buses. Seri Iskandar is a town and also the district capital of Perak Tengah in Perak. UTP, Universiti Teknologi Mara and Kolej Profesional Mara are located in Seri Iskandar. Perak Tengah is the administrative district in Perak. There is a library, district education office, police headquarter, JKR engineering office and other offices located at Perak Tengah. Universiti Teknologi Mara, Perak is the branch campus of Universiti Teknologi Mara, Shah Alam, Selangor with more than 10,000 students.

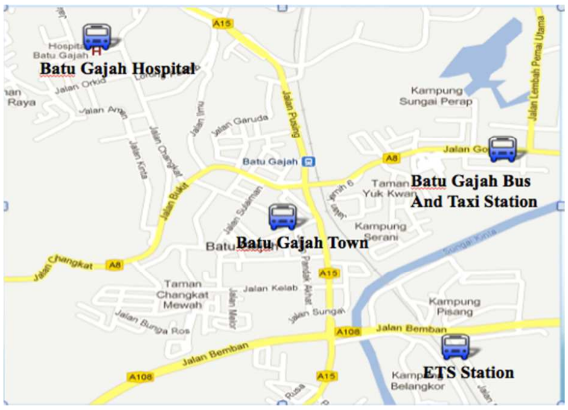

Fig 1. Hotspots around Batu Gajah ETS Station

B. Shortest Path between Hotspots

Googlemaps is used to identify the shortest distance in kilometers (km) from hotspot to hotspot (also known as station). The shortest distances are used as the input of GA to find the optimized route. Googlemaps uses a shortest path algorithm similar to Dijkstra's Algorithm [9]. Table 1 shows the shortest path generated through Googlemaps between all the hotspots. For example, the shortest path from Batu Gajah ETS Station (Station 1) to Bandar Seri Iskandar (Station 8) is 21.5km, which is shown in Fig.2.

TABLE 1
SHORTEST PATH BETWEEN THE HOTSPOTS

STATION	1	2	3	4	5	6	7	8	9	10
1	/	2.5	3.8	3.9	13.4	17.5	19.8	21.5	22.6	22.8
2	2.4	/	1.6	1.3	15.4	15.6	18	19.5	20.5	20.9
3	4	1.5	/	2.8	12.8	16.8	19.5	21	22	22.5
4	3.8	1.6	2.8	/	12.9	16.9	19.6	21	22	22.5
5	14.3	12.1	13.6	12.7	/	4.4	7	8.4	9.5	10
6	18.2	16.1	17.6	16.6	4.4	/	2.8	4.2	5.3	5.8
7	20.9	18.8	20.2	19.3	7	2.8	/	1.5	2.5	3
8	22.3	20.2	21.7	20.7	8.6	4.3	1.5	/	1.5	2.1
9	25.1	23	24.5	23.5	11.4	7.1	4.4	5.2	/	2.2
10	23.9	21.8	23.6	22.4	10.2	5.9	3.1	4	1.5	/

Station 1: ETS Station

Station 2: Batu Gajah Town

Station 3: Batu Gajah Bus and Taxi Station

Station 4: Batu Gajah Hospital

Station 5: Tronoh

Station 6: Universiti Teknologi Petronas (UTP)

Station 7: Taman Maju Bus Station

Station 8: Bandar Seri Iskandar

Station 9: Universiti Teknologi Mara Bandar Seri Iskandar Bota Perak

Station 10: Perak Tengah

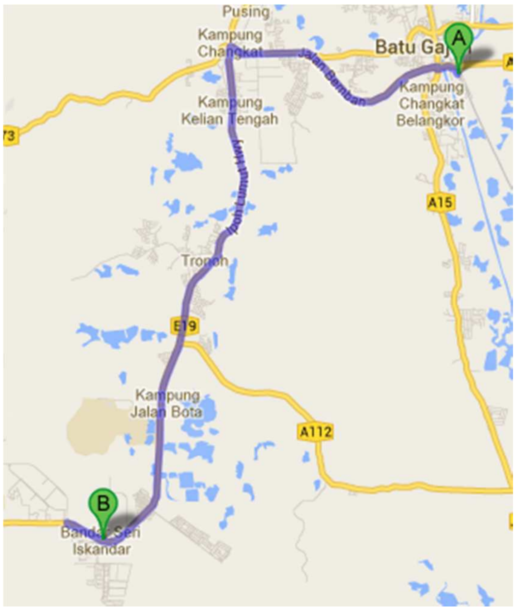

Fig. 2. Shortest Path from Batu Gajah ETS Station to Bandar Seri Iskandar

C. Genetic Algorithm (GA)

Genetic algorithm is a solution for combination optimization problem that imitates the biological process of reproduction. In genetic algorithm, each of the iteration is known as the next generation with new chromosomes that made up of combination of different genes. Genetic algorithm uses the concept of survival of the fittest. Through the evolutionary reproduction, the population of chromosomes will have to compete and survive. At the end of evolution, only the fittest chromosome can survive.

Each individual of a population is treated as a gene that is connected to form a long string. These strings are known as chromosomes. They represent the possible solutions of the optimization problem. In the GA based on route optimization, a chromosome contains the parameters such as number of station travelled, number of passenger per station and fare per station (as shown in Fig. 3) as these are the parameters that have to be optimized in the genetic algorithm for route optimization.

Each Individual Station Travelled, ***S***	Number of passenger per station, ***P***	Fare Per Station, ***F***

Fig. 3. Chromosome Structure

The proposed fitness function derived for the GA evaluates the individual chromosome based on net profit. The total distance travelled, multiplied by petrol per kilometer is the total cost. On the other hand, the sum of number of passenger per station, multiplied by fare per passenger of total station travelled is the total revenue. So, the net profit is found by using the total revenue minus the total cost. Logically, the aim is to maximize the net profit, which can also be achieved by minimizing the net lost.

The fitness function can be given below

$$N = R\text{-}C \quad (1)$$
$$C = D.K \quad (2)$$
$$R = P.F \quad (3)$$

where N is the net profit, R is the revenue, C is the cost, D is the total distance travelled, K is the petrol cost per kilometer, P is the total number of passenger per station and F is the fare per passenger of all the station travelled.

The first part of genetic algorithm is to solve for the best maximum number of station for the routing plan. Roulette wheel is employed for the selection process. First of all, the genetic algorithm creates a large population of chromosomes that are the routing plans. A fitness value has been assigned to each routing plan with individual total maximum station based on the fitness function. The higher the fitness value, the higher chances that number of maximum station will be selected from the roulette wheel. After this, the two fittest number of maximum station with the highest chances will be selected for crossover. The crossover of the random number of station is based on the crossover rate. The chances for the random number of station that will be altered depend on the mutation rate. The procedures are repeated to obtain the best maximum number of station.

The second part of genetic algorithm is to solve for the best routing plan. The routing plan population is grouped into four individuals routing plan per group. The fitness function is assigned to each individual routing plan of the group. The best individual routing plan from each group is selected based on the fitness value to go through four cases of mutation process in order to produce four new individuals of routing plan. The four mutation processes are switching a random segment, flipping the middle segment, point mutation and shifting. These new individuals of routing plan are evaluated based on their fitness value. The procedures are repeated to obtain the best individual of routing plan.

GA is used to obtain the most optimized route based on the following parameters and settings. The identified shortest distance from hotspot to hotspot at the Batu Gajah area is set as the input. The first station and the last station are set to be the ETS Station. The number of passengers at each station is set to 5. The fare of each passenger is RM2 and the petrol cost per kilometer is RM0.54 [10]. The total number of stations that the bus will travel to is 9 stations excluding the starting and ending station that is the ETS station.

IV. Simulation Results

The simulations are performed using Matlab. The GA code used has been modified from [11]. Firstly, the GA is set to find the results of the case for travelling to 3 stations. These results are then compared with the manual calculation by using the brute-force method, for verification purpose. Secondly, the results of most optimize route for the case that considers travelling to the total stations of 9 stations is obtained. Last but not least, the effect of petrol cost is also explored.

A. Travelling to 3 Stations

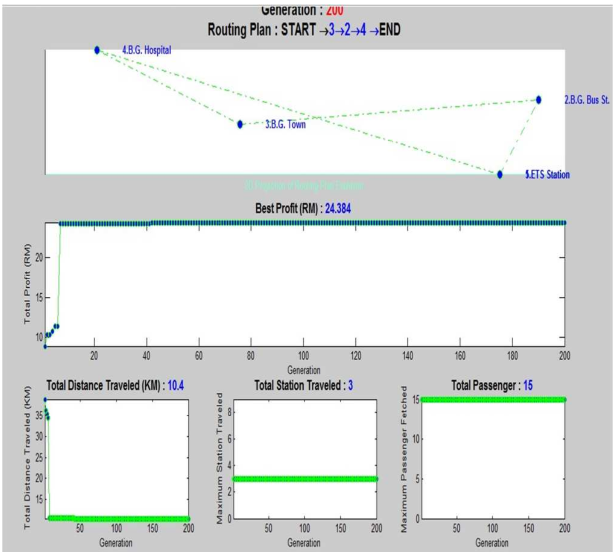

Fig. 4. Results of Genetic Algorithm for 3 Stations

Figure 4 shows that the most optimized routing plan obtained by the GA for 3 stations is from the START - Station 3 - Station 2 - Station 4 - END (ETS Station - Batu Gajah Bus Station - Batu Gajah Town - Batu Gajah Hospital - ETS Station). The results also show the best profit of RM 24.384, with a total distance travelled of 10.4 km, total station travelled of 3 stations and total passenger of 15 people.

TABLE 2
Results of Brute-Force method for 3 Stations

Routing Plan	Total Distance Travelled (km)	Best Profit (RM)
1-2-3-4-1	2.5+1.6+2.8+3.8 =10.7	(15x2)- (10.7x0.54)=24.222
1-2-4-3-1	2.5+1.3+2.8+4 =10.6	(15X2)- (10.6x0.54)=24.276
1-3-2-4-1	**3.8+1.5+1.3+3.8= 10.4**	**(15x2)- (10.4x0.54)=24.384**
1-3-4-2-1	3.8+2.8+1.6+2.4= 10.6	(15X2)- (10.6x0.54)=24.276
1-4-2-3-1	3.9+1.6+1.6+4 =11.1	(15x2)- (11.1x0.54)=24.006
1-4-3-2-1	3.9+2.8+1.5+2.4= 10.6	(15X2)- (10.6x0.54)=24.276

The manual calculation results from the brute-force method are shown in Table 2. As can be seen, the 3rd highlighted row of Table 2 shows the most optimized routing plan which gives the best profit of RM 24.384. The corresponding routing plan is 1-3-2-4-1, which is the same optimized route obtained from using the GA, as shown in Fig. 4. Hence, the optimized route found by using the GA is verified. The verification using 4 stations has also been performed but was not included in the paper due to brevity.

B. Travelling to 9 Stations

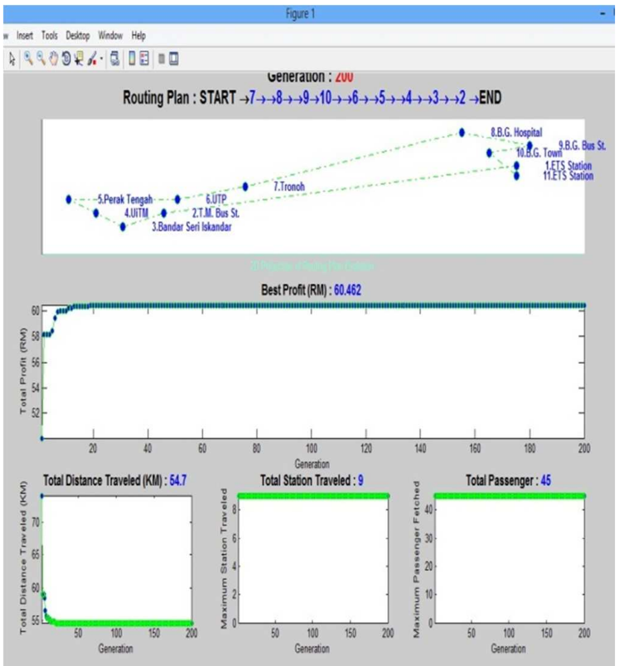

Fig. 5. Results of Genetic Algorithm for 9 Stations

Figure 5 shows the most optimized routing plan for the total station of 9 stations is from the START - Station 7 - Station 8 - Station 9 - Station 10 - Station 6 - Station 5 - Station 4 - Station 3 - Station 2 – END (ETS Station - Taman Maju Bus Station - Bandar Seri Iskandar - Universiti Teknologi Mara - Perak Tengah - Universiti Teknologi Petronas – Tronoh - Batu Gajah Hospital - Batu Gajah Bus Station - Batu Gajah Town - ETS Station). The results also show that the optimized route gives the best profit of RM 60.462, the total distance travelled of 54.7 km, total station travelled of 9 stations and total passenger of 45 people. The optimized route obtained by GA makes a lot of sense because it covers the group of further stations contiguously and the nearby group of stations contiguously. Therefore, the route is able to minimize the distance of travel which in turn minimizes cost.

C. Effect of Petrol Cost

In this subsection, the effect of petrol cost on the total profit and number of stations travelled will be investigated. With the setting of maximum station bound of 9 stations, fare per passenger of RM 2 and 5 passengers at each station, the GA is used to run for different amount of petrol cost per km from RM 0.1 to RM 3.0 with RM 0.1 increments.

The graph in Fig. 6 shows that when the petrol cost per km increases, the total profit will generally decrease, as expected. However, the rate of decrease slows down when, the petrol cost per kilometer, K = RM 1.4. The reason for this will be apparent later. It is also interesting to note that the total profit reaches a negative value of – RM 0.16 when $K \geq$ RM 2.9. This means that the feeder bus cannot operate profitably when the petrol cost per km reaches RM 2.9.

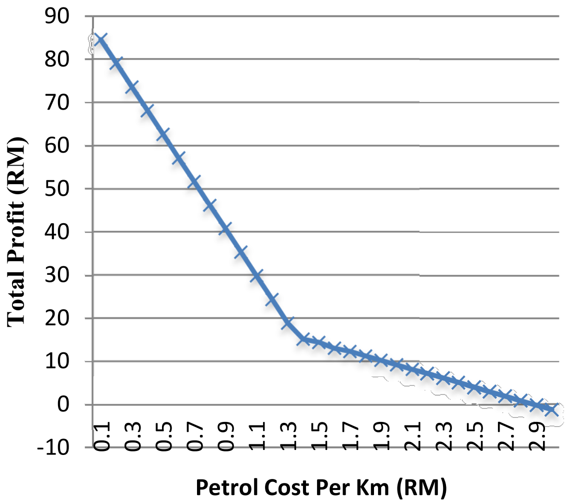

Fig. 6. Effect of Petrol Cost on Total Profit

Fig. 7 shows the effect of petrol cost on the total number of stations travelled. It can be seen that when the petrol cost increases, the number of total station travelled is constant at 9 stations and decreases abruptly to 3 stations when K = RM 1.4. It then remains constant at 3 stations even with further increases in petrol cost. Upon closer inspection, this behavior can be explained by noting that there are 3 stations that are near to the Batu Gajah ETS station that are the Batu Gajah Town, Bus Station and Hospital. The other group of 6 stations is much further away. So when the petrol cost increases, it has become less economical to travel far to the other stations. In summary, the increase of petrol cost will result in the decrease of total profit and total number of stations travelled.

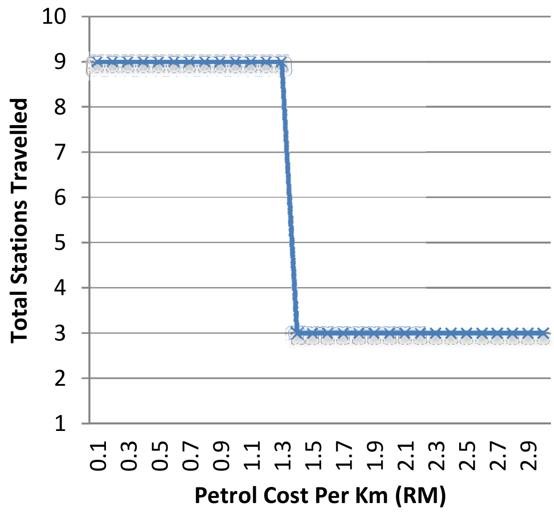

Fig. 7. Effect of Petrol Cost on Total Stations Travelled

V. Conclusions

The ETS has provided a safe, fast and cost effective way to travel between the two major cities of Kuala Lumpur and Ipoh. What is still lacking though is the connectivity between the commuters' homes and workplaces to the ETS stations. An effective solution to this problem is an efficient feeder bus system that brings commuters to the ETS stations remains a significant problem. In this work, a design of a wide coverage feeder bus route that is also effective and efficient in terms of service has been achieved. The genetic algorithm has been used to optimize the feeder bus route. The optimization is performed to attain the best operation profit. As a case study, the route optimization problem of the feeder bus for the Batu Gajah ETS station was considered. The inputs of the GA are the shortest distance between each pair of stations, the petrol cost per km and the fare per passenger. Simulation results show that the GA is robust enough and is able to solve the route optimization problem to obtain the widest coverage feeder bus route with effective and efficient service.

Future work includes incorporating more realistic parameters including different number of passengers depending on the specific station, capacity of different buses, interdependent parameters and also how these parameters are affected during peak hour rush.

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REFERENCES

[1] Electric Train Service [Online]. Available: http://en.wikipedia.org/wiki/Electric_Train_Service

[2] KTM ETS Fare Structure and Schedules [Online]. Available: http://landasan.info/services/ktmb/ets/schedules/

[3] P. Shrivastava and M. O'Mahony, "Modeling an Integrated Public Transportation System - A Case Study in Dublin, Ireland," *Transportation Research*, 2005.

[4] P. Shrivastava and M. O'Mahony, "A Model for Development of Optimized Feeder Routes and Coordinated Schedules- A Genetic Algorithm Approach," *Transport Policy*, vol. 13, pp. 413-425, Sep. 2006.

[5] Q. Zhang, E. Xu, Z. Wang and Y. Dong, "DNA Algorithm on Optimal Path Selection for Bus Travel Network," in *Proc. Bio-Inspired Computing*, Oct. 2009, pp. 1-4.

[6] B. Shi, C. Zhao and Y. Zhang, "Route Optimization for Bus Dispatching Based on Improved Ant Colony Algorithm," in *Proc. Computer and Automation Engineering Conference*, Feb. 2010, pp. 807-810.

[7] F. Ciaffi, E. Cipriani and M. Petrelli, "Feeder Bus Network Design Problem: A New Metaheuristic Procedure and Real Size Applications," *Procedia – Social and Behavioral Sciences,* vol. 54, pp. 798-807, Oct. 2012.

[8] C. Rego, D. Gamboa, F. Glover, C. Osterman, "Traveling Salesman Problem Heuristics: Leading Methods, Implementations and Latest Advances," *European Journal of Operational Research*, vol. 211, pp. 427 - 441, June 2011.

[9] Google Maps-it's just one big graph [Online]. Available: http://blogs.cornell.edu/info2040/2011/09/14/google-maps-its-just-one-big-graph/

[10] Survey of Motor Vehicle Use, Australia, 12 months ended 30 June 2012 [Online].Available: http://www.abs.gov.au/ausstats/abs@.nsf/mf/9208.0

[11] Student Dave's Tutorial on Genetic Algorithm [Online].Available:http://studentdavestutorials.weebly.com/traveling-santa-claus-genetic-algorithm-solutions.html.