International Journal of Combinatorial Optimization Problems and Informatics, 11(2), May-Aug 2020, 1-12. ISSN: 2007-1558.

www.editada.org

Editorial for Volume 11 Number 2: Electric School Bus Routing Problem for Smart Cities

Ocotlán Díaz-Parra[1], Jorge A. Ruiz-Vanoye[1], Alejandro Fuentes-Penna[2], Alberto Ochoa Zezzatti[3]*
Ernesto Cruz-Hernández[1], Salma Estrada-García[1], Antonio Alvarado-Pérez[1].
[1] Universidad Politécnica de Pachuca, México.
[2] Centro Interdisciplinario de Investigación y Docencia en Educación Técnica, México.
[3] Universidad Autónoma de Ciudad Juárez, México.
jorge@ruizvanoye.com

Abstract. The use of electric vehicles (cars, motorcycles, scooters, trucks, buses) in the cities is an essential component so that cities can be considered smart cities. In this paper, we propose a mathematical model for the Electric School Bus Routing Problem which aims to minimise costs and optimise transportation times and cost of the students. We propose a Genetic Algorithm with a pre-Selection Operator, Tournament Selection Operator, Crossover-K Operator, and Mutation-S Operator to solve the Electric School Bus Routing Problem (SBRP).
Keywords: School Bus Routing Problem; Electric School Bus; Smart Cities.

Article Info
Received Sep 11, 2018
Accepted Sep 11, 2019

1 Introduction

The use of cars to petrol and diesel fuels causes the emission of carbon dioxide, nitrogen oxide, carbon monoxide and the molecules of hydrocarbons that do not burn during combustion to the environment of the planet.

The Electric School Bus Routing Problem (E-SBRP) or School Electric Bus Routing Problem is the management of the Electric School Bus Fleet for the transportation of the students; each student assigned to a particular bus which must be routed efficiently to pick up (or return home) each of the students. The E-SBRP is a variant of an np-hard problem called School Bus Routing Problem (SBRP). The SBRP is a significant problem in the management of the school bus fleet in the transportation of students; each student assigned to a particular bus which must be routed efficiently to pick up (or return home) each of these students (Newton and Thomas, 1974).

Several researchers in the world seek to reduce the emission of pollutants and the optimization of the resources dedicated to public transport. In this paper, we propose a mathematical model for the Electric School Bus Routing Problem which aims to minimize costs and optimize transportation times and cost of the students. Section II presents related works found in the transportation using electric vehicles; section III presents the mathematical model, section IV presents the experimentation describing instances used, in section V is the conclusions and references.

2 Related Works

Taweepworadej and Buasti (2016) used an algorithm for the design of electric vehicle charging station in circular paths in electric buses to optimise the time of arrival and energy consumption.

Jang, Suh and Kim (2016) introduce an electric transit bus (ETB) system that uses the innovative wireless power transfer technology, called on-line electric vehicle (OLEV). In the ETB system, the wireless-charging infrastructure installed under the road charges the fleet of electric buses that is operative over that road. The technology is innovative in that the battery in the bus charge while it is moving over the charging infrastructure.

Leou and Hung (2017) designed a model that considers the capacity and loads of energy of an electric bus to minimize energy costs.

Abdelrahman et al. (2018) present a platform for accurate mathematical modelling of the propulsion system of electric cars, a hardware-in-the-loop (HIL) real-time experimental verification case study of a General Motor Chevrolet Volt for power, control systems, and the mechanical systems.

Gambella et al. (2018) consider a station-based electric car-sharing system which allows one-way trips and uses relocation to re-balance the vehicle distribution.

Paulraj et al. (2018) used Artificial Neural Network to monitor and fault diagnosis of a motorbike engine. In this case, the authors used a simple feature extraction algorithm to extract the features of motorbikes' engine based on the noise signal.

Dorvigny Dorvigny et al. (2008) propose a navigation solution of low cost whose principle is the use of the extended filter of Kalman and GPS measurements for estimating speed and position an autonomous vehicle.

Swaraj Ravindra Jape and Archana Thosar (2017) presented a comparative table with a set of electric vehicle motors.

Alegre-Buj (2017) completed a thesis where mentions high oil consumption and the greenhouse effect causing the railcars. Based on this proposal, the author presents the modelling of electric vehicles and parallel hybrids where it makes a comparison chart of different aspects of electric vehicles, such as the power of the engine, type and size of battery, weight, and analyse the changes that affect the performance and the distance travelled.

Sánchez-Arango (2016) proposed a mathematical model to integrate the optimal location of battery Exchange stations and minimise the problem of electric vehicle routing.

Sheefi (1985) proposed the transportation problem as an analogy of supply and demand, where the user has to make a decision based on price, quality, flow, the travel mode, distribution of trips, the route, and so on. This set of decisions is focused on having a balance. The author's proposal is based on a unified framework to build a graphical and network representation.

Chen et al. (2018) developed a mathematical model for charging stations considering the limitations between the capacity and distance, is considered the existence of charging stations and switch stations

3 Electric School Bus Routing Problem

This article proposes a variation of the SBRP transport model proposed by Gavish and Shlifer (1979) for the school bus routing problem, in the variant taking into account restrictions for electric buses. In the variant of the model are taken into account the energy buses load restrictions to optimize the time on routes and times of each bus battery charging. Endpoints of the cost of transportation, demand and route of buses on each route are considered.

$$z = \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=0}^{M} C_{ij} X_{ijk} \tag{1}$$

$$\sum_{k=1}^{M}\sum_{j=0}^{n} X_{ijk} = 1 \quad i = 1,2,3,\ldots n \tag{2}$$

$$\sum_{k=1}^{M}\sum_{i=0}^{n} X_{ijk} = 1 \quad j = 1,2,3,\ldots n \tag{3}$$

$$\sum_{k=1}^{M}\sum_{j=0}^{n} X_{0jk} = \sum_{k=1}^{M}\sum_{i=0}^{n} X_{i0k} = M \tag{4}$$

$$\sum_{j=0}^{n} X_{ijk} = \sum_{j=0}^{n} X_{jik} \quad i = 1,2,3,\ldots n \;\; k = 1,2,3,\ldots M \tag{5}$$

$$U_{ik} + U_{jk} + (n - m + 1)X_{ijk} \le (n - M) \;\; 1 \le i, j \le n, i \ne j, k = 1,2,\ldots M \tag{6}$$

$$\sum_{i=0}^{n}\sum_{j=0}^{n} X_{ijk} q_i \le Q \quad k = 1,2,\ldots M \tag{7}$$

$$\sum_{i=1}^{n}\sum_{j=0}^{n} X_{ijk} t_{ij} \le \tau \quad k = 1,2,\ldots M \tag{8}$$

$$\sum_{i=0}^{n}\sum_{j=1}^{n} T\varepsilon u_{X_{ijk}} < \frac{Tt\varepsilon b_k}{4} + Ut\varepsilon b_k \tag{9}$$

$$Tcb_k < Wt_{es} \tag{10}$$

School buses are centrally located and have to collect waiting for students at n pick-up points and to drive them to school (Gavish and Shlifer, 1979). The equations 1 to 8 represent the behaviour of the problem of school vehicle routing originally proposed by Gavish and Shlifer (1979) which will be used in this variant to electric buses. The equations 1-8 mentions about the number of students that wait in pick-up point i is qi, (qi> 0, i = 1, 2, …, n). The capacity of each bus is limited to Q students ($qi \le Q$). The objective function of the School Bus Problem (Gavish and Shlifer, 1979) is composed of two costs: a) cost incurred by the number of buses used, b) driving cost (fuel, maintenance, drivers salary, and others), subject to operational constraints, Cost a or b have to minimize. For a given M of buses, let $X_{ijk}i$, j = 0, 1, 2, …, n, k = 1, 2,…, M be variables that attain the value 1 if pick-up points i and j are visited by the k^{th} bus, and pick-up point j is visited directly after i. Otherwise, X_{ijk} is 0. Let U_{ik}, i = 0, 1, …, n, k = 1, 2, …, M be variables that may attain any value. The objective of the SBRP is to find variables X_{ijk} and U_{ik} that minimize z. Where C_{ij} = cost of driving from point i to point j, C_{ij} is a function of the distance between i and j and the driving time, $C_{ij} = \begin{cases} Cij \forall i,j,i \ne j, \\ \infty \forall i = j, \end{cases}$, t_{ij} = driving time from point i to point j, q_i = a quantity to be loaded (or unloaded) at i, k = set of constraints characterized by the nature of the problem, where $k = (1, 2, ..., K) \in K$. The three dimensional assignment problem could be transformed into a regular assignment problem by duplicating M - 1 times the row and column corresponding to city 0, and obtaining an assignment problem with dimensions ($n + M$) by ($n + M$). Constraints ensure the formation of exactly M tours, where each one passes through the school (Gavish and Shlifer, 1979). Equation 8 represents the restriction of energy battery bus times.Equation 9 considers the fourth part of the total energy time of the battery for a X_{ijk} tour that is being considered the number of routes for the collection and delivery of students, so that students get to school on time and return in time to each of the points considered in the model. $T\varepsilon u_{ijk}$ represents the energy-time used by the k vehicle in the course of i. $Tteb_k$ represents the energy total time of the car's battery k .It must not exceed by the sum of the energy-time used by the k vehicle to finish the route into X_{ijk} segments.

The energy-time used by each vehicle is represented by the $T\varepsilon u_{ij}$ variable. For this model has been considered to add a parameter of units of energy time parameter ($Ut\varepsilon b_k$) to ensure that the energy remaining battery time is not zero.

Equation (10) represents the restrictions of time concerning student input/output window named as Wt_{es} which must not be exceeded by the energy charging time of the battery of the k vehicle.

Time Window to recharge should not be increased at the time of the day of classes of the student. Where Tcb_k represents the time of charging the battery of the vehicle. The points considered in this model are in the depot. In such a way that recharges batteries only vehicles may be made when they are in the tank already is in the departure or arrival of each tour.

This variant is considering the regulation of the speed in a range of [60-65] mph. The vehicle uses an average energy consumption ($T\varepsilon p_k$) obtained by the characteristics of the type of battery used. This feature can be the calculation of the average maximum distance that can go that bus in a certain time before it completes its route without having to recharge the battery.

Table 1 shows some of the characteristics of the most frequently used for electric bus batteries.

Table 1. Batteries used for electric bus (VEIC,2018).

Type of Bus	Battery of the Bus	Capacity (passengers)	Time of loading	Time energy used / hr	Distance Travelled	Speed Limit
A-TransTech	FIAMM Sodium Nickel	25	2-2.5 hr 50% 8 hr for 100%	85KWh	75 miles	60 mph
A-Lion	LG Lithium-ion	34	3 hr for 50% 7 hr for 100%	160KWh	> 150 miles	60 mph
C-Starcraft eQuest XL	FIAMM Sodium Nickel	48	2-2.5 hr 50% 8 hr for 100%	85KWh	65-75 miles	60 mph
C- eLion	LG Lithium-ion NMC	72	2 hr for 50% 5.2hr for 100%	104KWh	75 miles	60 mph
C- Thomas Built Buses	XALT Lithium-ion NMC	81	8 hr for 100%	155KWh	120 miles	65 mph

The characteristics in table 1 of the types of electric buses to be used in each instance will be a homogeneous fleet of type C - eLion by selected by the characteristic of the charging time which must be less than the time which passes the student at the school. An instance of the electric school bus routing problem is in Table 2.

Table 2.E-SBRP instances.

NS	SS	PS	ML	SEE	F	VN	VC
STWb	STWdue	TBV	TEV				
BS	XCO	YCO	SN	EPT	DPT	MRT	MWT
0	X_0	Y_0	SN_0	EPT_0	DPT_0	MRT_0	MWT_0
…	…	…	…	…	…	…	…
0	X_n	Y_n	SN_n	EPT_n	DPT_n	MRT_n	MWT_n

Where NS: Number of School (single or multiple),SS: Surroundings of Service (urban or rural), PS: Problem scope (morning, afternoon, both), ML: Mixed Load (allowed or not allowed), SEE: special-education students (considered or not considered), F: Fleet mix (homogeneous fleet or heterogeneous fleet), VN: Vehicle Number, VC: Vehicle Capacity, STWb: School Time Windows Begin, SWTdue: School Time Windows Due, BS: Bus Stop, XCO: X Coord., YCO: Y Coord., SN: Student Number, MRT: Maximum Riding time, EPT: earliest pick-up time, DPT: Due pick-up time, MWT: Maximum Walking Time or distance, TBV: Type of the vehicle's battery, TEV: Energy time of the vehicle

The bioinspired algorithm for solving the E-SBRP is a genetic algorithm with a selection operator of the tournament, crossover-k operator, and a mutation operator based on mutation-S operator. The Genetic Algorithm is considered as bio-inspired algorithm (Ruiz-Vanoye and Díaz-Parra, 2010) because realise the transfer of genetic material to offspring or the inheritance of genes by subsequent generations. The temporal complexity of the bio-inspired algorithm for solving E-SBRP in the worst of the cases is: $T(n) \in O(\mathrm{n}^3)$ .The Code of the Genetic algorithm to solve E-SBRP is:

Input: Vehicle Capacity, Bus Stop, X coord., Y Coord., Student Number (Demand), Bus Stop time window (earliest pick-up time, Due pick-up time, Maximum Riding Time, Maximum Walking Time), TBV: Type of the vehicle's battery, TEV: Energy time of the vehicle.
Output: Total Bus travel distance, Number of Buses and the routes.

0. Begin

1. Generate not-random initial population (one individual) of n chromosomes, a suitable solution for the problem, by the use of the clusterization population pre-selection operator. Clusterization population pre-selection operator (Díaz-Parra et al., 2010) is used only forgenerating the initial population (an individual with n chromosomes, set of genes or vehicles) of an intelligent way for evolutionary and genetic algorithms. The initial population is generating by a data-mining technique called by the k-means algorithm (MacQueen, 1967), which classifies the groups of data with similar characteristics. They cluster the geographical location (X coord. and Y Coord.) of the E-SBRP.

2. New population. Create a new population by repeating the following steps until the new population is complete:

a) Generate a random population of n chromosomes based on the non-random initial population or the population of the new generation, interchanging of the random way a pair of genes of the individuals.
b) Fitness. Evaluate the fitness f (x) of each chromosome x in the population.
c) Selection operator. Select two parent chromosomes from a population according to their fitness (tournament operator). The Tournament selection operator (Wetzel, 1983) consists of randomly taking two individuals from the population and to generate a random number r (between zero and one). If r<k, where k is a parameter, selects the best one of the individuals, on the contrary, selects worse, both individual ones are given back to the initials so that they can be selected again.
d) Crossover operator. The crossover-k operator consists of finding two points randomly in the individual (rand1 and rand2) and to search in the individual the corresponding genes to make the crossover.The crossover-k operator generates two individuals from two individuals. The operator takes two individuals randomly from the population and generates two random numbers, and then the search of the nodes corresponding to the random numbers is realized in individual 1. Once identified the nodes to cross, the operator searches the nodes in the individual 2. Since the positions of the corresponding nodes in both individuals have been identified, the crossing is realized of nodes in individual 1 (the first individual), to generate the second individual, the crossover is realized in the individual 2. The crossover is realized as long as the nodes to cross differently. Figure 1 is the mechanism of operation of the crossover-k operator.
e) Mutation operator. Mutation-S (Figure 1) consists of detecting the genes with significant distances in the matrix of Euclidean distances and to compare with the genes involved in the individual that minor generates distances to change, verifies the restriction of time and vehicle capacity. Mutation-S consists of detecting what of all the genes that conform to the individual is the one that involves major distances. On the basis of the gene of greater distance the one realizes a search in the matrix of Euclidean distances with each one of the genes involved in the individual that minor generates distances is the gene candidate to change, next to identify the gene candidate, verifies the reductions of area of time window and vehicle capacity, if the then restrictions are not violated comes to realize the mutation.

3. Accepting. Place new offspring in a new population.

4. Replace. Use the newly generated population for a further run of the algorithm.

5. Test. If the end condition is satisfied, stop, and return the best solution in the current population.

6. Loop. Go to step 2.

7. End

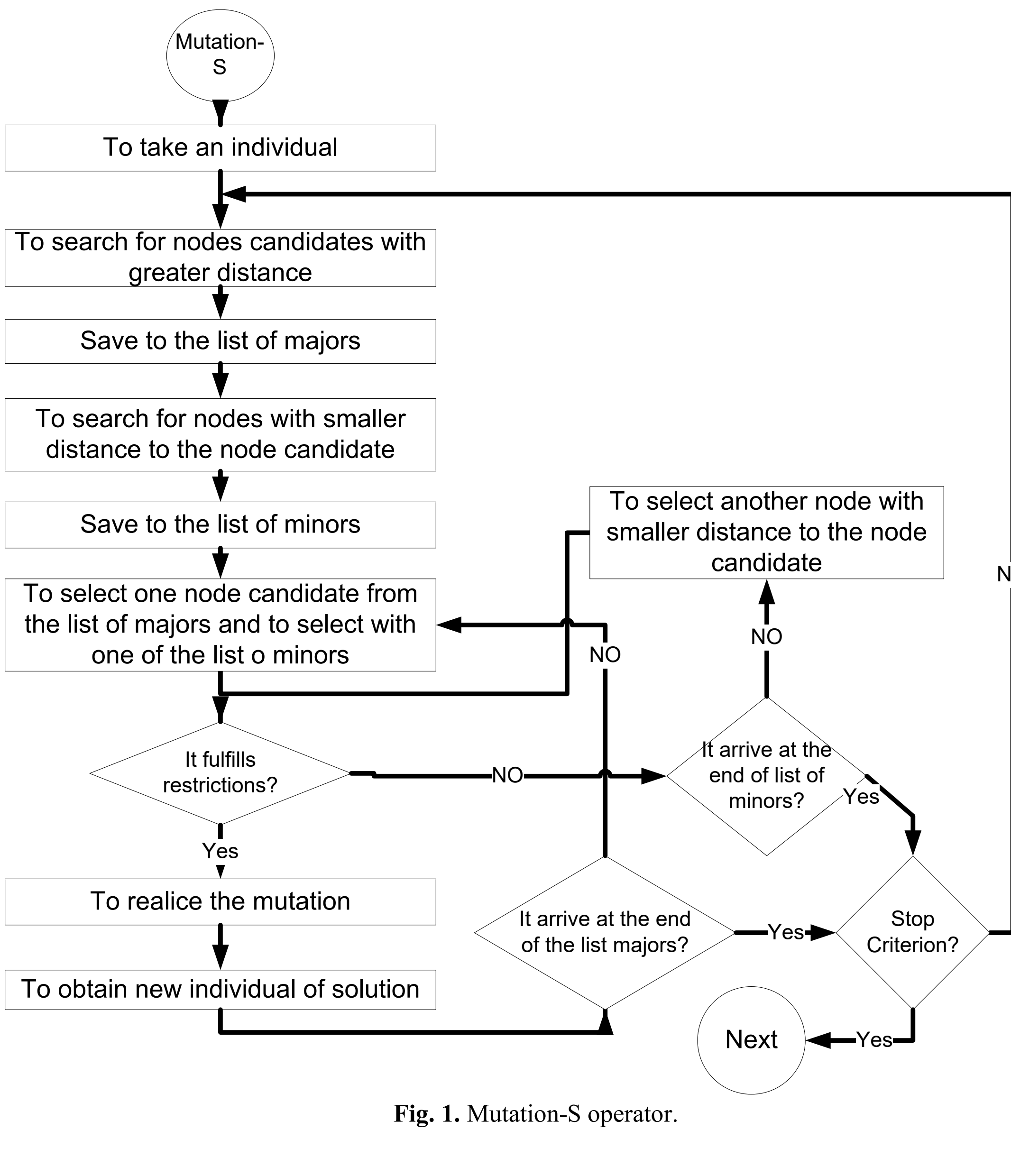

Fig. 1. Mutation-S operator.

4 Experimentation

The experimentation was carried on HP Proliant Server with AMD Athlon II 235e Dual-Core Processor and memory of 4 GB and the algorithm was developed using Visual C++ v.6. Moreover, others results were obtained using the CPLEX software to find the optimal cost of E-SBRP. We use the instance set E1 (Number of Schools: single, Surroundings of Service: Urban, Problem scope: Morning, Fleet mix: Homogeneous, vehicle capacity: 40, Bus Stop: 200. The urban means routes inside the city, morning means 7:00-9:00, the homogeneous fleet is the vehicle capacity equal in all the fleet) of the School Bus Routing Problem Library-SBRPLIB (Díaz-Parra et al., 2011). The SBRPLIB inspired in a real-life situation in Mexico.

The characterization of the SBRP instances are: Number of School (NS): single or multiple, Surroundings of Service (SS): urban or rural, Problem Scope (PS): morning, afternoon, both, Mixed Load (ML): allowed or not allowed, Special-Educations Students (SEE): considered or not considered, Fleet mix (F): homogeneous fleet or heterogeneous fleet, Vehicle Number (VN), Vehicle Capacity (VC), School Time Windows Begin (STWb), School Time Windows Due (SWTdue), Bus Stop (BS), X Coord. (XCO), Y Coord. (YCO), Student Number (SN), Maximum Riding time (MRT), Earliest Pick-Up Time (EPT), Due pick-up time (DPT), Maximum Walking Time or distance (MWT), TBV: Type of the vehicle's battery, TEV: Energy time of the vehicle. In table 3 are the results of the Genetic Algorithm with an initial population from which realized a clustering to obtain a list of individuals.

Table 3. Some results obtained from the Genetic algorithm (30 times for each instance).

Instances	*Genetic Algorithm*		*CPLEX*	
	Total Bus Travel Distance	*Buses*	*Total Bus Travel Distance*	*Buses*
E-SBRP-E1-1	10185.19	35	10180.00	35
E-SBRP-E1-2	10965.97	36	10965.97	36
E-SBRP-E1-3	11266.22	36	11166.33	35
E-SBRP-E1-4	15214.01	35	15214.01	35
E-SBRP-E1-5	12851.75	36	12851.75	36
E-SBRP-E1-6	12582.34	36	12582.34	36
E-SBRP-E1-7	12494.22	36	12494.22	36
E-SBRP-E1-8	9818.49	36	9818.49	36
E-SBRP-E1-9	9818.49	36	9818.49	36
E-SBRP-E1-10	11280.01	36	11260.09	35
E-SBRP-E1-11	10279.03	34	10279.03	34
E-SBRP-E1-12	11428.98	33	11428.98	33
E-SBRP-E1-13	14031.38	35	14031.38	35
E-SBRP-E1-14	10035.33	34	10035.33	34
E-SBRP-E1-15	10216.76	37	10116.26	36
E-SBRP-E1-16	11165.36	36	11165.36	36
E-SBRP-E1-17	10302.56	38	10302.56	38
E-SBRP-E1-18	11005.69	34	11005.69	34
E-SBRP-E1-19	10558.33	37	10558.33	37
E-SBRP-E1-20	11542.48	36	11542.48	36
E-SBRP-E1-21	10958.58	36	10958.58	36
E-SBRP-E1-23	12692.01	34	12692.01	34
E-SBRP-E1-24	11521.35	34	11521.35	34
E-SBRP-E1-25	10025.53	37	10015.33	36
E-SBRP-E1-26	11018.24	35	11018.24	35
E-SBRP-E1-27	11597.19	36	11597.19	36
E-SBRP-E1-28	11515.74	38	11415.12	37
E-SBRP-E1-29	11490.97	36	11490.97	36
E-SBRP-E1-30	11365.43	33	11365.43	33

E-SBRP-E1-31	11090.65	36	11090.65	36
E-SBRP-E1-32	12272.99	35	12272.99	35
E-SBRP-E1-33	11890.97	36	11890.97	36
E-SBRP-E1-34	13112.94	38	13012.72	37
E-SBRP-E1-35	11491.31	37	11491.31	37
E-SBRP-E1-36	10138.13	31	10138.13	31
E-SBRP-E1-37	10108.62	33	10108.62	33
E-SBRP-E1-38	10006.01	36	10006.01	36
E-SBRP-E1-39	11744.12	37	11744.12	37
E-SBRP-E1-40	11200.10	34	11200.10	34
E-SBRP-E1-41	11102.05	36	11102.05	36
E-SBRP-E1-42	11381.58	36	11281.24	35
E-SBRP-E1-43	12074.00	34	12074.00	34
E-SBRP-E1-44	12513.76	36	12513.76	36
E-SBRP-E1-45	11537.06	34	11537.06	34
E-SBRP-E1-46	11565.18	36	11565.18	36
E-SBRP-E1-47	11222.52	35	11122.31	34
E-SBRP-E1-48	11080.48	35	11080.48	35
E-SBRP-E1-49	10903.73	33	10903.73	33
E-SBRP-E1-50	10342.50	33	10342.50	33

The case study is related to one school (the Autonomous University of Morelos State or UAEM) of the Cuernavaca city of Mexico, Surroundings of Service: Urban, Problem scope: Morning, Fleet mix: Homogeneous, vehicle capacity: 40, Bus Stop: 22, electric buses (homogeneous fleet of type C-eLion battery). The urban means routes inside the city, morning means 7:00-9:00, homogeneous fleet is the vehicle capacity equal in all the fleet.

The Autonomous University of Morelos State is a public institution of higher education more important coverage, and more important in the state of Mexico's Morelos, with headquarters in the capital, the city of Cuernavaca. The institution has 27 academic units, five centers and two research units located in 3 campuses campus installed in various municipalities in the state.

A survey (30 surveys peer faculty or 660 surveys) to the students of the 22 university faculties to obtain real information about university transport and analyzing their behaviour topropose to transport college students benefit from the UAEM. The representative sample taken from the student population is comprised of 30% of students on campus north (Chamilpa) of the UAEM, the university has a total of 11,504 senior students spread over three campuses, North Campus, east campus and south campus. Figure 2 contains the bus stations necessary to transport some students of the University and table 4 show the E-SBRP instance of the University.

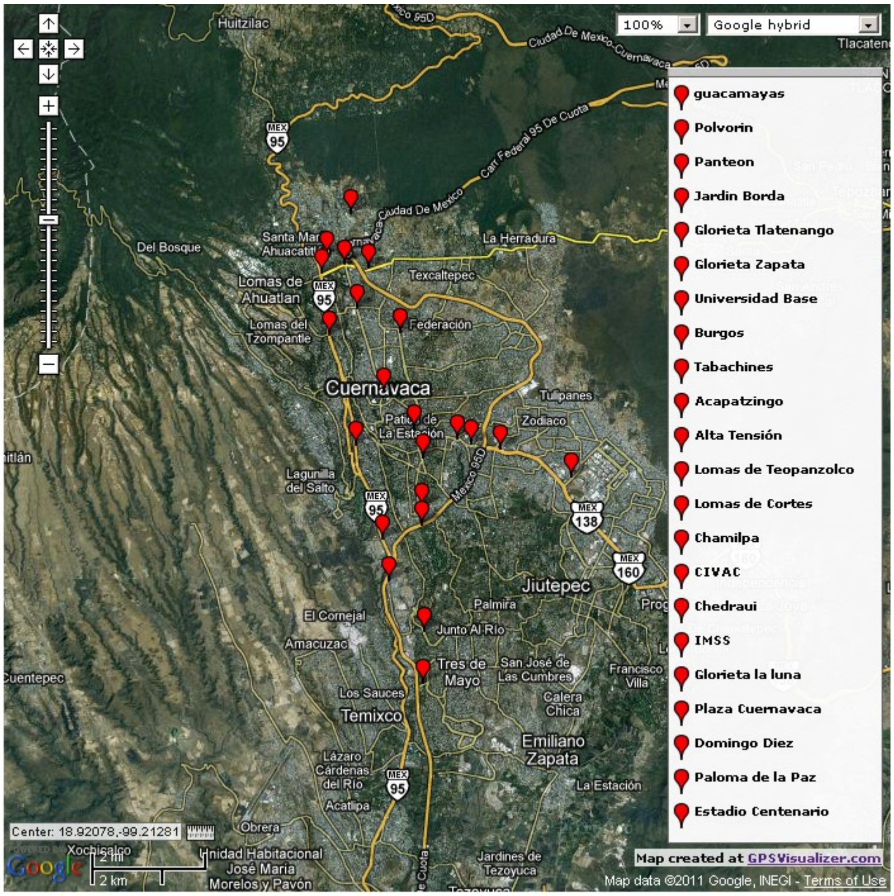

Figure 2. Cuernavaca and Bus Stop locations of UAEM.

Table 4. E-SBRP Instance of UAEM.

Bus Stop	**Location (GIS)**	**Student Number**	**Earliest Pick-up time**	**Due pick-up time**	**Maximum Riding Time**	**Maximum Walking Time or distance**
Universidad Base	18.98099, -99.23879	0	700	900	10	0
Glorieta Zapata	18.96569, -99.24671	3	510	511	3	8
Glorieta Tlaltenango	18.94991, -99.24459	10	533	534	3	10
Jardín Borda	18.92159, -99.23755	2	500	501	3	9
Panteón	18.89760, -99.23010	4	518	519	3	6
Polvorin	18.88668, -99.22845	9	547	548	3	7
Guacamayas	18.87372, -99.21895	3	505	506	3	7
Burgos	18.86056, -99.21925	10	538	539	3	7

Tabachines	18.90117, -99.21946	9	540	541	3	7
Acapatzingo	18.90564, -99.21942	12	542	543	3	7
Alta Tensión	18.91818, -99.21933	2	539	540	3	9
Lomas de Teopanzolco	18.92569, -99.22152	4	704	705	3	7
Lomas de Cortes	18.95053, -99.22543	8	749	750	3	10
Chamilpa	18.96709, -99.23401	4	702	703	3	3
CIVAC	18.91359, -99.17891	2	700	701	3	10
Chedraui	18.92046, -99.19835	4	719	720	3	3
IMSS	18.92176, -99.20604	9	716	717	3	4
Glorieta la Luna	18.92331, -99.20987	12	751	752	3	5
Plaza Cuernavaca	18.93505, -99.22981	5	736	737	3	2
Domingo Diez	18.95662, -99.23698	7	727	728	3	4
Paloma de la Paz	18.96813, -99.24066	7	752	753	3	6
Estadio Centenario	18.97032, -99.24527	6	604	605	3	8

In Table 5 are the total bus travel distance of the genetic algorithm used to solve the E-SBRP of UAEM, and in table 6 are the best route.

Table 5. Results of the E-SBRP Instance of UAEM.

Total Bus Travel Distance	Number of Buses
1717.639358	3
1818.539493	3
1818.556720	3
1919.586404	3
1919.631402	3
1919.498600	4
1919.6325360	4
1919.6925580	4
2020.549677	4
2020.618819	4
2020.782089	4
2020.898991	4
2741.742000	4
2020.898991	4
2741.742000	4

Table 6. Best Route for UAEM instance.

Vehicles	Routes
1	Guacamayas, Polvorin, Panteón, Jardín Borda, Glorieta Tlaltenango, Glorieta Zapata, Universidad Base.
2	Burgos, Tabachines, Acapatzingo, Alta Tensión, Lomas de Teopanzolco, Lomas de Cortes, Chamilpa, Universidad Base.
3	CIVAC, Chedraui, IMSS, Glorieta la Luna, Plaza Cuernavaca, Domingo Diez, Paloma de la Paz, Estadio Centenario, Universidad Base.

The computed solution will allow a saving of 1,000 dollars per week to transport the students of the University of the State of Morelos, which will allow investing money in other aspects such as scholarships, social and regional support, which would allow the growth of the State or country.

5 Conclusions

The use of bus electric for transporting students in a city is of great importance. If the city is to be considered a smart city should have sustainable and efficient transport to transport the society of that city.

REFERENCES

Abdelrahman, A., Algarny, K., and Youssef, M. (2018). A Novel Platform for Power Train Modeling of Electric Cars with Experimental Validation Using Real-Time Hardware in-the-Loop (HIL): A Case Study of GM Chevrolet Volt 2nd Generation. *IEEE Transactions on Power Electronics*.

Arango, J.D.S., and Echeverri, M.G. (2016). *Modelo matemático para el problema integrado de ubicación óptima de estaciones de intercambio de baterías, ruteo de vehículos eléctricos y reducción de pérdidas de energía en la red de distribución* (Doctoral dissertation, Universidad Tecnológica de Pereira. Facultad de Ingenierías Eléctrica, Electrónica, Física, y Ciencias de la Computación. Maestría en Ingeniería Eléctrica.).

Buj, M.S.A. (2017). *Modelado del vehículo eléctrico e híbrido paralelo por medio de Matlab/Simulink y planificación de estaciones de carga mediante sistemas de información geográfica y algoritmos genéticos* (Doctoral dissertation, UNED).

Clairand, J., and Vera, J. (2014). Modelado de Vehículo Eléctrico en un Trayecto Típico de la Ciudad de Quito. *Revista Politécnica*, *36*, 19-24.

Chen, Y.W., Cheng, C.Y., Li, S.F., and Yu, C.H. (2018). Location optimization for multiple types of charging stations for electric scooters. *Applied Soft Computing*, *67*, 519-528.

Díaz-Parra, O., Ruiz-Vanoye, J.A., and Zavala-Díaz, J.C. (2011). School bus routing problem library-SBRPLIB. *International Journal of Combinatorial Optimization Problems and Informatics*, *2*(1), 23-26.

Díaz-Parra, O., Ruiz-Vanoye, J.A., and Zavala-Díaz, J.C. (2010). Population pre-selection operators used for generating a non-random initial population to solve vehicle routing problem with time windows. *Scientific Research and Essays*, *5*(22), 3529-3528.

Díaz-Parra, O., Ruiz-Vanoye, J.A., Bernábe Loranca, B., Fuentes-Penna, A., and Barrera-Cámara, R. A. (2014). A survey of transportation problems. *Journal of Applied Mathematics*, *2014*.

Dorvigny Dorvigny, D., Hernández Santana, L., and García García, D. (2018). Algoritmo de navegación integrada para vehículos autónomos con tecnología de bajo costo. *Revista Cubana de Ciencias Informáticas*, *12*(3), 121-139.

Gambella, C., Malaguti, E., Masini, F., and Vigo, D. (2018). Optimizing relocation operations in electric car-sharing. *Omega*, *81*, 234-245.

Gavish, B., and Shlifer, E. (1979). An approach for solving a class of transportation scheduling problems. *European Journal of Operational Research*, *3*(2), 122-134.

Hu, J., Wu, J., Peng, H., Peng, Q., and Huang, Q. (2017, March). Application of Fuzzy Logic Algorithm for Optimization of Control Strategy in Electric Vehicles. In *Proceedings of the 2017 IEEE 2nd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), Chongqing, China* (pp. 25-26).

Jang, Y.J., Suh, E.S., and Kim, J.W. (2016). System architecture and mathematical models of electric transit bus system utilizing wireless power transfer technology. *IEEE Systems Journal*, *10*(2), 495-506.

Leou, R.C., and Hung, J.J. (2017). Optimal Charging Schedule Planning and Economic Analysis for Electric Bus Charging Stations. *Energies*, *10*(4), 483.

MacQueen, J. (1967, June). Some methods for classification and analysis of multivariate observations. In *Proceedings of the fifth Berkeley symposium on mathematical statistics and probability* (Vol. 1, No. 14, pp. 281-297).
Newton, R.M., and Thomas, W.H. (1974). Bus routing in a multi-school system. *Computers & Operations Research*, *1*(2), 213-222.
Paulraj, M.P., Majid, M.S.A., Yaacob, S., and Zin, M.Z.M. (2008, December). Motorbike engine faults diagnosing system using neural network. In *Electronic Design, 2008. ICED 2008. International Conference on* (pp. 1-6). IEEE.
Park, J., and Kim, B.I. (2010). The school bus routing problem: A review. *European Journal of operational research*, *202*(2), 311-319.
Ruiz-Vanoye, J.A., and Díaz-Parra, O. (2011). Similarities between meta-heuristics algorithms and the science of life. *Central European Journal of Operations Research*, *19*(4), 445-466.
Sheffi Y. (1985). Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods. Prentice-Hall, Englewood Cliffs, NJ.
Swaraj Ravindra Jape and Archana Thosar (2017). Comparison of Electric Motors for Electric Vehicle Application. *International Journal of Research in Engineering and Technology*. 6(9).
Taweepworadej, W., and Buasri, P. (2016). Vehicle Routing Problem for Electric Bus Energy Consumption and Planning. *Journal of Advances in Agricultural & Environmental Engineering*, *3*(2), 224-226.
Veicorg. (2018). Veicorg. Retrieved 8 November, 2018, from https://www.veic.org/Media/success-stories/electric-school-bus-charging-equipment-installation-guide.pdf
Veicorg. (2018). Veicorg. Retrieved 8 November, 2018, from https://www.veic.org/Media/success-stories/types-of-electric-school-buses.pdf