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School Bus Routing Problems and Solutions for Smart Cities – A Case Study

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16.1 Introduction

Cities today present important challenges in terms of growth and diversification of problems. One of the most serious problems related to the smart cities is the mobility of its citizens. Here transport can play an important role as it can mobilize large numbers of citizens from one place to another but the times used in the journeys each day are longer and more conflicting.

The big cities in the world are organizing various programs to encourage new strategies of mobility by increasing the number of vehicles but this increase of vehicles further increases the pollution level. The most common means of transport are private vehicles, private services and public services.

Smart cities look for people living in urban spaces to be the direct beneficiaries of new technologies and seek to incorporate information and communication technologies (ICT) for their utility. The incorporation of these technologies and tools make the services efficient. Also, with these new

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technologies and techniques the smart cities can become innovative, competitive, attractive and resilient, thus improving human lives. Technological development is progressing, and alleviating the problems of daily life are a constant task: there are currently an endless number of applications that seek to improve the activities of human beings, and many of them have better information systems, cost reductions, time reductions, better support teams, aspects of health, and so on.

Modern school life has a host of problems that must be addressed to offer a better education. The new education strategies seek to integrate with new technologies, that is, ICT within their classrooms which ultimately provides a better approach with students, improve the relationship between administration, teachers and students.

School life is not limited to the spaces of the classroom, it is constructed from a great variety of areas and moments, for example, relations of classmates; class assignments at school and outside of school; recreational activities; family life; virtual life; travel times and so on. According to population growth, urban areas are farther away, moving from one zone to another is taking longer time. Any trip in the city is via congested avenues due to the increasing number of vehicles and the number of stoplights which cause slow moving traffic and accessibility problems.

Vehicle routing problem (VRP) is an optimization issue that has been used for approximately 50 years for its benefits and applicability, and even today it is still used in the search for better routes of mobility (Lewis et al. 2018). Concerning the problem of transfers within the town, Gakenheimer (1997) indicated that there were disturbing records that accessibility between places had already disappeared. Mobility problems have been studied in more detail since 1998 when the problems caused lost times and important effects in the economic, environmental and social areas, examples of this problem are presented below

- Rio de Janeiro, Brazil, has recorded taking up to 90 minutes to get from one place in the city to another;
- Bogotá, Colombia, where a person can take 60 minutes to move from a place to another;
- Manila, with speeds of seven miles per hour due to vehicular congestion; and
- Bangkok, which, due to the amount of traffic, there were stoppages recorded that, on average, is equivalent to 44 days lost in traffic jams in a year.

Approaches to solving school-related transportation problems are insufficient This is because many of the school districts are the proprietors of the school buses, and one of the big dilemmas is how to manage them efficiently and effectively, which means establishing specific schedules (the time school begins and ends, which can be changed); and optimizing the resources is another determining factor (both the bus and the driver). One of the main problems with school transportation resides in the small location and management of bus stops. This mismanagement of bus routes is reflected in the high maintenance costs of school buses and prolonged time students spend on buses while being taken to school or back home. The primary objective of this chapter is to demonstrate and explain the identification of efficient school bus routes utilizing the particle swarm optimization (PSO) method.

Among the strategies of school service planning, there are two key elements: the route and the scheduling of the service. To resolve this scenario, we combine both elements, as it is important to look for the best alternatives in the complexity of the situations presented, because both are a priority and there needs to be a balance.

It is very important to understand that in 87 societies around the world of different sizes, including Yakutia, the Brazilian state of Minas Gerais and Macau, they want to solve their traffic problems, and the most relevant is to be able to solve the school transport problems.

The following questions were considered for this study:

1. How do you assign a bus stop to a student?
2. How many stops would be required for all students?
3. Are the selected stops relevant?
4. How can the best route be chosen?
5. Are there any alternate routes?
6. How will these decisions affect alternative paths?
7. What will be taken into consideration when deciding on a route ?
8. Does the school bus meet the set time?
9. How do you generate the planning of routes?

Based on the previous problems and questions, the purpose of this chapter is to develop a homogeneous multimodal system to solve the problem of ensuring efficient travel while minimizing waiting times. This plan incorporates trip compatibility, covering both the scheduling problem and the routing problem.

16.2 School Bus Routing Problem (SBRP)

This work originates at the Federal University of Technology Akure / Computer Science Department, Akure (The Federal University of Technology Akure 2019) and different studies related to school bus routing problem

(SBRP) (Shafahi, Wang and Haghani 2017) where they proposed a variation on the vehicle routing problem (VRP). The SBRP is a problem-solving model that involves the route that will follow a limited number of school buses along scheduled routes that are defined in an efficient and optimal way. The SBRP can be divided in five sub-problems (Kang et al. 2015):

a. data preparation: this defines the data required to set up stop allocation, the route definition and the scheduling;
b. selection of stops: this step consists in assigning a stop to each of the students who are users of the buses, which must fulfill the objective of being located closest to where they live;
c. route generation: this covers the decision regarding the order in which the school bus will visit each stop;
d. arrival time: this covers setting the time the student must arrive at school; and
e. schedule of route: this deals with the allocation of school bus routes covering best fit, taking into consideration the time for which students must arrive at school while establishing plans to allow each school bus to transport students from the sector in which they live to their school.

The representation of the problem-solving process based on the SBRP in its five most important moments is presented in Figure 16.1.

The SBRP consists of at least two smaller sub-problems (Díaz-Parra et al., 2012):

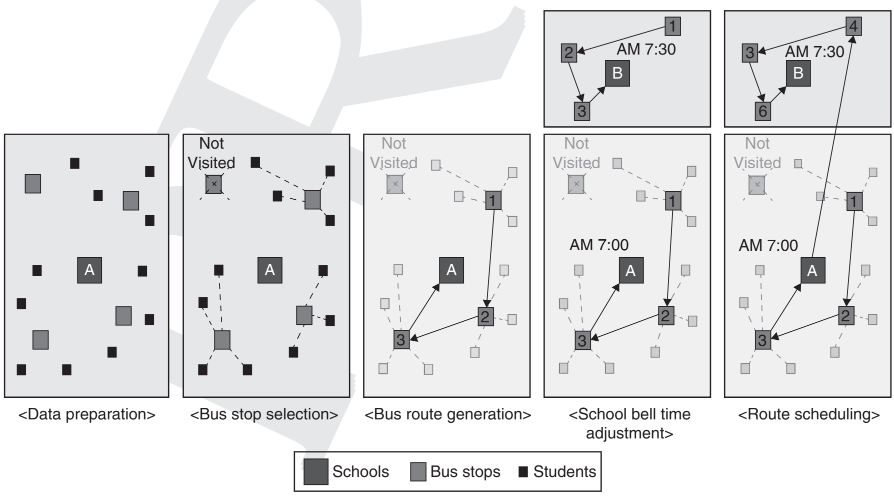

FIGURE 16.1
Representation of problems of school bus algorithm (Kang et al. 2015)

a. the selection of the appropriate bus stop, called "Bus Stop Selection", seeks to select a set of bus stops and assign students to these stops; and
b. "Bus Route Generation" is modeled and implemented to generate the necessary bus routes for a single school.

Furthermore, they established a series of restrictions related to the SBRP (Kang et al. 2015):

a. bus capacity: the maximum number of students that the bus may contain;
b. maximum travel time: the maximum time a student can stay in the bus;
c. time window: the time a bus takes to arrive;
d. homogenous capacity: buses with different capacities;
e. mixed load: different students from different school;
f. knowing the schedules of schools to maximize the number of routes by bus and to reduce the number of buses used for a multi-school system in a school district;
g. the programming of a specific route;
h. the start and end of each route of a bus for a multi-school system.

The results of different studies were indicated by Díaz-Parra (2012) and established seven main characteristics of the SBRP which all models must meet:

a. number of schools (one or multiple)
b. service environment (urban or rural)
c. scope of the problem (morning, afternoon, both)
d. multiple load
e. fleet combination objectives (number of buses used, total distance traveled by bus time taken)
f. total distance, distance of student walks, load balance
g. walk time or distance, earliest pickup time and the minimum number of students to create a route
h. The mathematical model.

In our revision of the literature, we found that the first users of the model of the SBRP date from 1974, when they tried to offer solutions for a problem where the institute had a single school bus and 80 stops. The aim was to propose an algorithm to solve a problem in a district, by the location of each school, the location of each student, the period of use of transportation by the student and the availability of buses (Díaz-Parra 2012). After this

TABLE 16.1

Application of school bus routing problem (SBRP)

Year	Title and references
2018	Using the Metaheuristic Methods for Real-time Optimization of Dynamic School Bus Routing Problem and an Application (Yigit, Unsal and Deperlioglu 2018)
2018	A Heuristic Algorithm for Finding Cost-effective Solutions to Real-world School Bus Routing Problems (Lewis and Smith-Miles 2018)
2018	A Bounded Formulation for the School Bus Scheduling Problem (Zeng, Chopra and Smilowitz 2018)
2018	The School Bus Routing Problem: An Analysis and Algorithm (Lewis, Smith-Miles and Phillips 2018)
2017	IoT-based School Bus Tracking and Arrival Time Prediction (Jisha, Jyothindranath and Kumary 2017)

publication, the applications of the SBRP have become more diverse and they have sought to solve a great diversity of problems. The new contributions to solving problems establishes the state-of-the-art of the investigations carried out using SBRP and indicates the benefits found. A chronological revision of issues related with this research is presented in Table 16.1.

New applications of the algorithm are made for the analysis of various topics, and one of them is to look for the safety of students en route to school, monitor arrival times, improve costs, reduce travel time and increase safety.

16.3 Particle Swarm Optimization (PSO)

PSO was presented for the first time in 1995 in order to create a graphic simulation in which schools are shown a choreography of fish or birds, to show the flows of robust synchronization and coordinated in different aspects (Kennedy and Spears 1998). This application allowed visualization of how the trajectories of the schools and their vectors are seen. The original PSO tests make use of a velocity vector to update the current position of each particle in the swarm. In other population studies it is indicated that the location of each particle is updated based on the social behavior of a population of individuals, the multitude in the case of PSO, which adapts to its environment by returning to promising regions that were previously discovered (Kennedy and Spears 1998). Members of a swarm do not know the behavior of the multitude itself, much less the environment in which they operate. However, the local expression of individuals is what defines the general conduct of the swarm. With this in mind, the PSO algorithm comprises a set of members or particles representing a point in a multidimensional space.

The population studies allow exploring behaviors in defined spaces where it is sought to explain an ideal position, previously defined in the function. Since PSO is oriented to a multidimensional space, it can be adapted to a two-dimensional problem proposed in SBRP, because this case must consider the bus ground displacement (Grosan, Abraham and Chis 2006). Also mentioned, the particles in the swarm explore the problem of space, looking for an optimal position, which is defined by a fitness function. The location of each particle depends on its own experience and that of their peers (other particles), therefore, each particle must have its memory. In addition, this memory saves the best position found, and this position is called personal best or Pbest. The results allow establishing generalized behaviors, such as:

a. homogeneity: the flock moves without a leader, even though temporary leaders seem to appear;
b. locality: the motion of each bird is only influenced by its nearest flock mates. Vision is considered the most important sense for flock organization;
c. collision avoidance;
d. velocity matching: attempt to match velocity with nearby flock mates;
e. flock centering: attempt to stay close to nearby flock mates.

16.4 Methodology

The area of study of our research was in El Paso, Texas. In these cities, the use of transportation is essential for the mobility of students to their schools which ultimately provides benefits to the students.

The city of El Paso, Texas borders with Mexico and adjoins the state of New Mexico. The movements of the school bus are constant because the city is large, and the school trips are by zones. The idea is obviously to transport the maximum number of students with minimum delays and so intelligence to create the best route is key. The transport service is important as it reduces travel cost and volume of vehicles on the road. To minimize the lost time at the school, it is a priority for the bus to arrive on time. In this line, the creation of routing is an appropriate strategy: more students traveling a minimal distance.

16.4.1 Noise Definition

Another factor that must be taken into consideration is “noise”. This data set presented extra considerations while defining the functionality of the PSO algorithm in its early stages. Some unexpected data points appeared and were classified as:

a. traffic: defined by common routes that people take to go to their jobs or other places; it should be ideal to identify these routes and try to avoid them.
b. special zones: defined by roads with special restrictions that involve speed limits. For example, hospitals, parks, railroad crossing, markets, places that cannot be accessed by driving or need to be accessed at a reduced speed or frequent stops need to be made.
c. roads with problems: roads being repaired or those that are damaged.

The following assumptions were also made as part of this investigation:

a. school buses are located at the center of a plane and they have to pick up students waiting at pickup points to be brought to school.
b. the number of students waiting at the collection point

$$\boldsymbol{i}\ is\ defined: qi,\ (qi > 0, i = 1, 2, \ldots, n) \tag{16.1}$$

Where

I = student in a school bus algorithm
Q = bus school in our model

c. The capacity of each bus is limited to a certain number of students.

$$Q\ (qi\ 0k) \tag{16.2}$$

Where:

Q = capability of school bus
qi = school bus with students
k = implements associated with student activities and carried by themselves.

The objective function of the school bus problem is composed of two costs:

a. cost incurred for the number of buses used, and
b. driving cost (fuel, maintenance, driver's salary and others), subject to operational restrictions, cost must be minimized.

16.4.2 Data Preparation

The study data is presented in Figures 16.2, 16.3 and 16.4, obtained using Google Maps (2019), covering main streets such as Fort Blvd., Dyer St., Pierce Ave., and Piedras St. The attendance depicted is for Rusk Elementary School.

A graph was created so each street's data could be stored. For the data recollection, the indicated sites where the students took the school bus were visited and the waiting times were measured.

16.5 Results and Discussions

According to the strategies established for answering the questions, the application of the methodology allowed to find the following results:

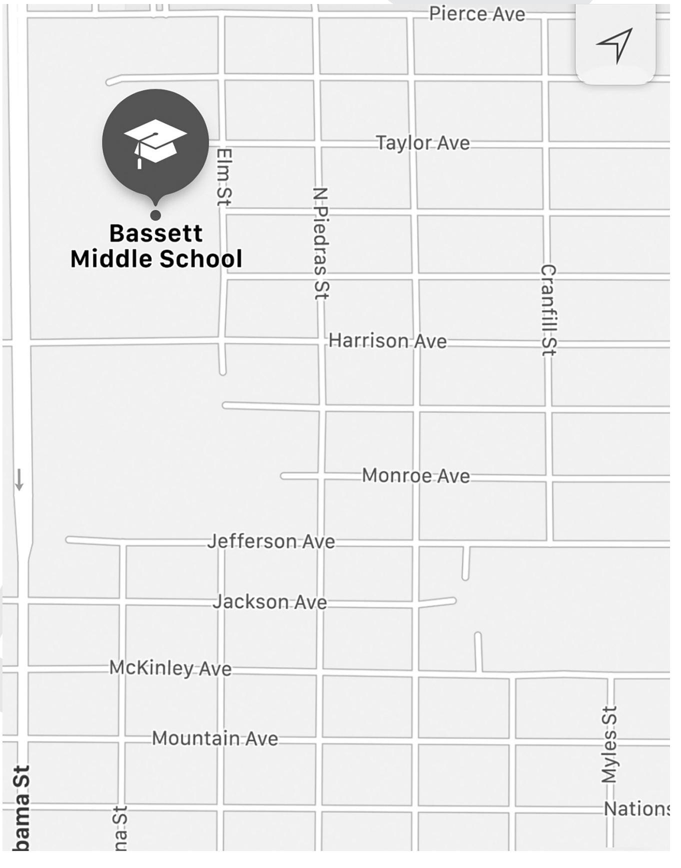

FIGURE 16.2
Area considered for the study (Google Maps 2019)

FIGURE 16.3
Bounded map of the study area (Google Maps 2019)

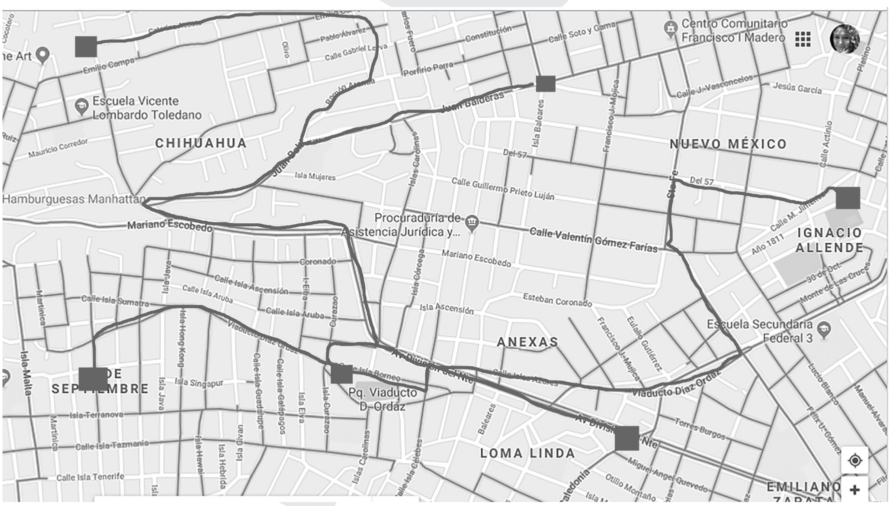

FIGURE 16.4
Area of study in metric system

16.5.1 Graph Creation

The nodes represent the street and the set of properties are identifications that distinguishes a node from another.

a. initial point: this is the initial position of the node;
b. final point: this is the final position of the node;
c. direction: West/South = 1, East/North = 2, Two ways = 0;
d. speed: the maximum speed in the street (m/h).

For the application of the algorithm, various activities carried out as described below:

a. image preparation: the image is a representation of the map;
b. then the user will click on the map to create a new node;
c. the system will then ask the initial and final points, directions and speed;
d. if the user doesn't finish the creation of all nodes in the map, repeat step b.

16.5.2 Operation of the Program

The proposed program works on an acquired image of Google Maps® (2019) in order to define the information required for the generation of the SBRP route. The first test consisted in the run of several destination points. For reasons of operation and subsequent increase in the complexity of the sectors where the stops were located, it sought to provide greater security. It is possible to define each of the points of the route as to where to have a bus stop based on the number of students that use each of the stops. This is done according to their location closest to their home.

Figure 16.5 shows the points of the bus stop of route 5. Figure 16.6 represents the route created using the bus stops, and Figure 16.7 shows the best route proposal.

The result of the run allows it to create the best route, and this route will enable it to define the time at which the school bus must present at each stop. As a result of watching time, it is determined that the approximate time for each stop was 5 minutes. It is essential to indicate that the number of students is different at each stop and the number of students is also different for each school so the number of buses required differs. A critical point is that the bus must reach its destination with sufficient time for the students to get off the bus.

Another critical aspect for the bus is the travel speed limit, which means that each bus must move at a maximum speed of 30 mph. Each of the routes involved in the study was monitored, and the data was assessed to generate

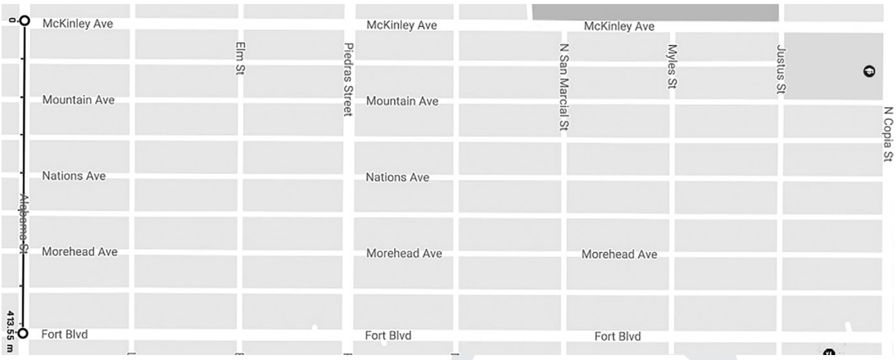

FIGURE 16.5
Creating street graph

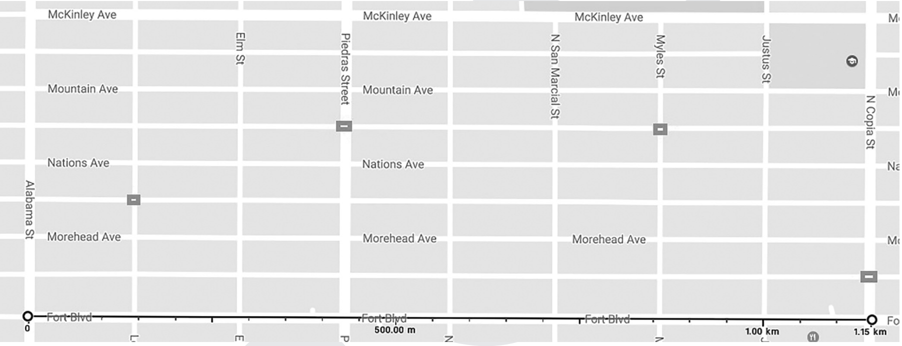

FIGURE 16.6
Particle search

route maps and waiting times. In Figure 16.8 the image of one of the routes carried out in the study is shown.

Conclusion

With this research, it can be identified that the use of genetic algorithms applied to SBRP can provide a more efficient plan for students to arrive at their school taking an optimal route during a tour based on a set of restrictions. Taking an optimal route implies a shorter path and in the shortest possible time. This type of genetic algorithm can help at people to solve problems associated with the school bus routes. Different types of algorithms were analyzed to see which of them could offer the most

FIGURE 16.7
Route definition

FIGURE 16.8
Visualization of school bus route in real-time in a school district in El Paso

optimal solution, so that school districts can make more efficient use of their limited resources, including school routes to be covered by a limited group of buses. It is worth mentioning that in each case study various characteristics of complex problems are presented and a different set of circumstances that affect them are presented, so the type of solutions that can be generated with this algorithm will be different for each case and situation in particular. Each case will require a different fit solution and consideration of the assumptions. This implies that although this is an optimal solution for a specific area, for another it will have to analyse the whole panorama and change all specifications and, probably, use a different type of algorithm. In the application of this type of solution, there is an enormous amount of work to be done in the future. One suggestion would be to analyse the same school bus route with another genetic algorithm and make a comparison of the results.

The use of the school bus algorithm improves the response times associated with transporting children in various societies around the world, regardless of the size of the society, such as Macao, the smallest, and Yakutia, the largest. The importance of these studies is based on the creation of new strategies to produce routes, seeking to improve sections of urban mobility within large cities, mainly those that have high-altitude areas and where large schools are located. These new routes allow internal traffic expense to become less expensive, the number of cars in circulation is reduced, long waiting times are reduced and pollutants are reduced from the number of vehicles circulating.

Suggestions for Future Research

From the results of this study, there are some following suggestions for future research:

a. automate the generation of sectors;
b. the sectors should be made in relation to the density of students per stop;
c. the number of buses available needs to be considered; and
d. the possibility to modify the location of the stops.

A key aspect of future research is to determine adequately when additional equipment must be brought to the school, and this entails the redistribution of spaces within the bus and time considerations, so that everything is sought in real-time, through the use of ubiquitous computing and telemetry.

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