A Smart Application for University Bus Routes Optimization

Alsayed Alsobky[1,2(✉)], Patrik Hrkút[3], and Miroslava Mikušová[4]

[1] Public Works Department, Ain Shams University, Cairo, Egypt
assobky@eng.asu.edu.eg
[2] Civil Engineering Program, German University in Cairo, Cairo, Egypt
alsayed.alsobky@guc.edu.eg
[3] Faculty of Informatics and Management Science, Department of Software Technologies, University of Zilina, Zilina, Slovakia
Patrik.Hrkut@fri.uniza.sk
[4] The Faculty of Operation and Economics of Transport and Communications, Department of Road and Urban Transport, University of Zilina, Zilina, Slovakia
mikusova@fpedas.uniza.sk

Abstract. This paper aims at providing a comprehensive solution for the university bus routing problem based on the design of flexible routes that are proposed to minimize the walking distances for the students as well as the total trip time considering the traffic condition and study schedule. It seeks to plan an efficient schedule for a fleet of university buses where each bus picks up students from various bus stops and delivers them to their designated universities overcoming various predefined constraints. The proposed routing technique was validated on one of the university bus lines at the German University in Cairo (GUC). This exercise investigated the applicability of this technique as well as its efficiency to minimize the walking distance, waiting time, and the trip travel time as well.

Keywords: Public transport · Bus route optimization
Intelligent transport systems · Smart applications

1 Introduction

The main objective of the university bus is to pick up students from the assembly points, close to their homes, and deliver them to the university campus in the morning and vice versa in the evening. This service is usually divided into a group of lines. Every line has certain destination and intermediate fixed assembly points. The line route is often selected to pass through the main arterials; while, the meeting points are located at the main intersections. These short routes cannot cover all districts and then some students must walk long distances or sometimes have to use other modes between their homes and the meeting points and vice versa. In contrast, picking up students from their homes will increase significantly the trip length and time. Furthermore, the fixed routes are not always appropriate because of the varied traffic condition as well as the varied study schedules.

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Applications of operations research in the field of the *school bus routing problem* usually has significant impact on the quality of pick-up and delivery service provided and consequently it results the reduction of operational costs of the service system. The development of models that are offering optimal solution used to be costly because the problem is quite complex and in its solving many constraints should be considered. For this reason, many efforts have been exerted to find novel approaches that can produce good solutions to such problems with low computational cost [1].

Park and Kim provides comprehensive overview of practical solutions for the school bus problem in [2]. Application based on using global positioning system to improve school bus routing and scheduling is presented in [3].

The approach implying a set of potential stops to which the students can walk is given in [4]. The goal of this mentioned study was to select a subset of stops that would be passed by the buses, determining which stop each student should walk to and develop a set of tours that minimize the total distance travelled by all buses.

Iskander, Jaraiedi and Emami in their paper [5] formulated a computerized multi-objective view of school bus problem. It considers transfers of the students that on one hand allow more flexibility in the bus network structure (operating costs reduction) but on other hand have an impact on the service level (the perceived service quality). Developed heuristic solution framework was compared with two solution concepts that do not consider transfers. Results show that allowing transfers reduces the total operating costs significantly while averaged maximum user ride times are comparable to solutions without transfers.

Díaz-Parra et al. presents in [6] an application of vertical transfer algorithm for school bus routing problem. Evolutionary algorithm that solves this problem on the base of clustered classification with time windows is presented in [7]. Heuristic solutions of routing school buses that are considering vehicle capacity, maximum distance of each route, time windows and minimum coverage of the breakpoints are provided as well in [8] by Corberán et al. The approach using Meta-heuristics algorithms is provided in [9, 10].

The most recent developments of presented topic [11–13] prove that bus routing problem remains alive.

2 Proposed Methodology

In this research, flexible routes are proposed to minimize the walking distances as well as the total trip time considering the traffic conditions and varied study schedules. First, every student is requested to fix the desired pickup point, according to his/her schedule, on the nearest collector road to minimize the walking distance. Second, *Google map* is used to recognize the traffic condition in terms of the shortest path between every two pickup points. Third, an optimization algorithm is used to arrange the pickup points based on the traffic condition. Finally, the student is informed with the estimated pickup time using a mobile application based on the traffic condition and the order of his/her pickup point.

The *mobile application* is used also to determine the participated students in every trip by allowing them to sign up for in the desired trip according to their study schedule but with enough time before the trip starts. In addition, the application is displaying the Google map to select the desired pickup point. The selected pickup locations are checked to be on the collector roads to avoid passing through local and unpaved roads. On the other hand, the participant students are informed with the estimated arrival time after sorting the requested pickup points based on the traffic condition at the trip time. In addition, the application is displaying the bus track and the arrival time update. On the other hand, the bus driver is informed, using Google map, by the arrangement of the pickup points during the current trip as well as the shortest route among them.

Google map is used to determine the shortest path as well as its travel time between every two pickup points in the same trip in addition to the university campus. A travel time matrix is created for the desired pickup points as well as the university campus. This matrix is used to select the shortest route starting at the university campus passing through all pickup points and ending again at the university campus. All algorithms solving the salesman problem can be used in this regard. However, the integer linear programming algorithm is suggested as it can be coded easily. In addition, extra constraints are used to avoid dividing the pickup points into multiple sub-tours.

2.1 Case Study

The proposed routing technique is validated on one of the university bus lines at the *German University in Cairo* (GUC). This exercise investigates the applicability of this technique as well as its efficiency to minimize the walking distance, waiting time, and the trip travel time. However, the implementation of the mobile application is out of the scope of this research due to the time and budget limitations. Authors will try later to implement this mobile application.

To validate the proposed routing technique, a real data was collected for the 1st settlement line in the GUC bus service. This line has more than 50 students located at different assembly points. Not all students attend every day or in certain time. The time schedule varies from student to another according to his/her registered courses, from day to another, and from week to another. There are six rounds every weekday to cover all times.

The fixed route is not suitable for this line as the passengers varies from trip to another. The driver tries before every trip to arrange the registered pickup points. The driver receives phone calls 20–30 min before the trip from the participant students to register in the coming trip and to be informed with the estimated arrival time. It’s a hard mental effort to remember the pickup point of each student and to arrange the points based on the traffic condition. It’s worth mentioning that some roads are one-way due to new construction on the road network in New Cairo City. Therefore, arranging the points should consider the valid road directions too.

2.2 Validation

One trip for the above-mentioned line was studied. In the future, instance sets of School Bus Routing Problem can be tested. The recorded data included the location of the drop off points, the actual route and travel time between every two successive drop off points. Figure 1 illustrates the location of GUC as well as the drop off points in a

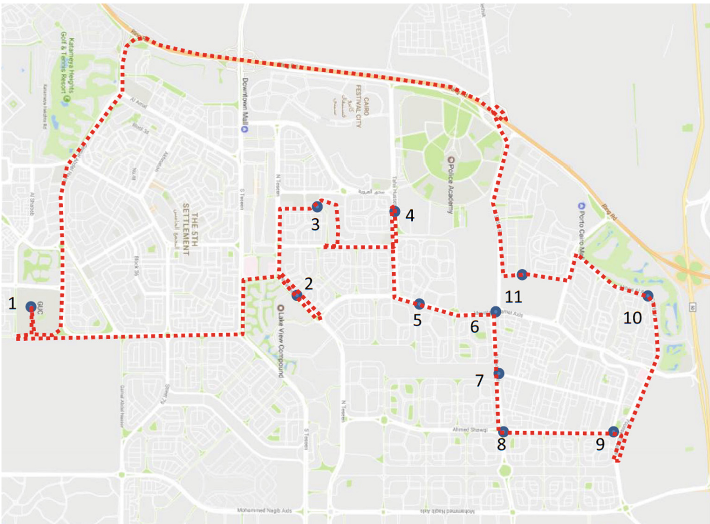

Fig. 1. The original university bus route before optimization.

certain round. It shows also the actual route, which consist of following ordered points: 1-2-3-4-5-6-7-8-9-10-11-1. The total trip time was 62 min.

To select the optimum route in terms of the total trip time, the *salesman problem* is considered. The home point is at GUC campus and the tour including all drop-off points should have the minimum travel time. To optimize the route selection, a travel time matrix including all drop-off points as well as the GUC campus location was measured using Google map. Each cell in this matrix represents the travel time of the shortest path between the row-head point to the column-head point according to the traffic conditions. This matrix is not symmetric due to some one-way roads.

Table 1 illustrates the travel time between every two points based on Google Map estimation. The shaded cells represent the travel time between every two successive points belonging to the actual return route selected by the driver.

There is enormous number of routes can be selected to include the ten drop-off points. The optimum route is a route out of 3,628,800 routes with the minimum total time.

The integer linear programming, as well as the sufficient constraints to avoid the multiple sub-tours as per *Miller-Tucker-Zemlin* [14], were used to find the optimum route. The objective function had 132 unknowns (121 for link incidents and 12 for the point orders). There were 33 equations to force the route to pass through points only one time. In addition, there were 90 inequalities to eliminate the sub-tours according to Miller-Tucker-Zemlin formulation [14]. The lower boundary for all unknowns was 0 for the link incidents and 2 for the drop-off points; while; the upper boundary for them was 1 for the link incidents and 11 for the drop-off points.

Solving the optimization formulation using Matlab software gives the optimum route in 0.03 s. The optimum route was computed as 1-2-3-4-5-6-11-10-7-8-9-1. The main difference between the optimum route and the actual route was in the order of

Table 1. Actual travel time matrix.

To / From	1	2	3	4	5	6	7	8	9	10	11
1	0	10	13	15	14	14	16	16	19	20	17
2	12	0	4	6	4	5	6	7	8	10	7
3	15	5	0	6	7	7	8	9	11	12	10
4	17	4	6	0	5	5	6	7	9	9	7
5	15	2	5	3	0	3	4	5	7	8	5
6	16	4	7	5	2	0	2	3	5	5	12
7	15	6	9	9	4	2	0	1	3	7	4
8	15	6	9	8	5	3	1	0	2	8	5
9	7	7	11	10	7	5	3	2	0	7	7
10	21	8	11	9	6	4	6	7	5	0	5
11	17	8	10	9	5	4	6	6	7	5	0

points 9, 10 and 11 as indicated in Fig. 2. In addition, the return trip was changed from the ring road which was suitable for returning from point 11 to be from point 9 via Ahmed Shawqi corridor. The total time for the optimum route was 51 min. The time reduction due to the proposed route represents 18% in the total travel time.

In the above exercise, authors have maintained the assembly points to compare only the impact of changing the route. Although, changing the meeting points to be closer to students' homes will increase the route time, using the proposed technique will optimize the route based on the new points and then decrease the walking distances.

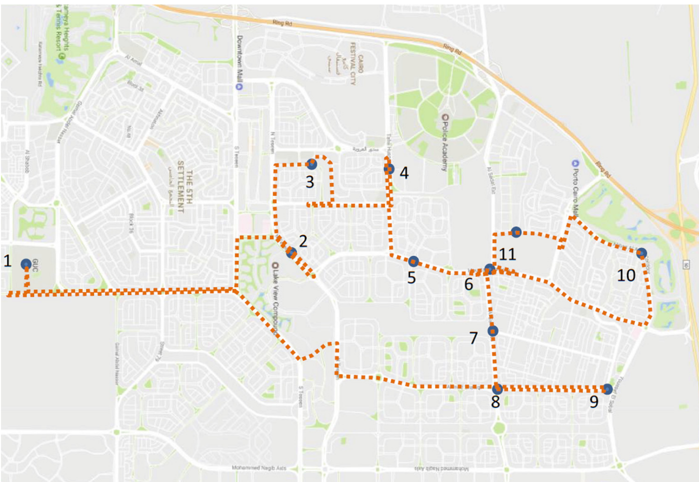

Fig. 2. The bus route after optimization.

3 System Architecture

As mentioned in above text, an application is necessary to be developed to allow students to add their schedule and to set the nearest pick up point. The driver must be informed about all students, when and where they prefer to get on. A system collecting data from users in real time and network connection is necessary. Nowadays almost all university students own mobile phones, so the online requirements could be easily fulfilled.

Architecture of the proposed system can be either of *peer-to-peer* [15] or *client/server* type [16]. Both architecture types have their pros and cons. The main advantage of peer-to-peer architecture (Fig. 3) is its decentralized character, no addition servers are needed. In this case, the information about student preferences is spread from device to device and one device can resend the information to others. On the other hand, this approach brings a problem with communication among clients. Although no one to one connection between clients is necessary and the data can be resent, some clients couldn't be accessible due to firewall restrictions or due to limited network access [15].

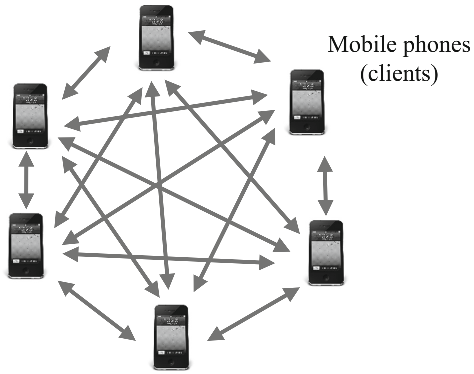

Fig. 3. Peer to peer network of mobile phones.

This kind of applications seems better to use client/server architecture (Fig. 4). Indeed, a centralized server is necessary, but it brings more positive effects for the system. Clients need to communicate only with the server and there is no communication between clients. Information is stored in a central database and all computations are executed on the server. Server then exposes the results on their interface and client can retrieve all necessary information about route stops and bus departures/arrival times.

The proposed system consists of application server, clients, and communication subsystem. Application server will serve as a heart of the entire system. It will contain the following components:

- relational database, where data will be stored;
- business logic module for optimized route computing (e.g. Matlab and Google Maps API);
- data interface for client communication.

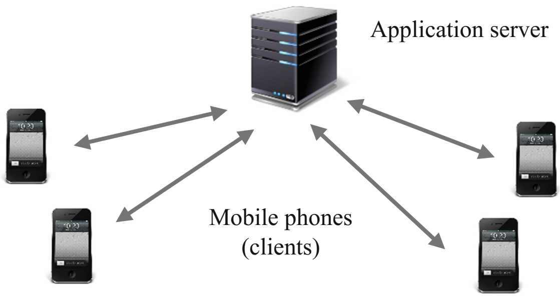

Fig. 4. Proposed client/server architecture.

The interface will provide clients with information about planned departure of the bus from its stop. The clients will authenticate and then send desired pickup point and departure time. We suggest implementing the interface as a *RESTfull service* [17]. This service paradigm enables a quick client-side development.

The client could be implemented as a native application for Android and Apple iOS, but these applications need to be developed separately. Another approach is to create a web based application with advanced technologies, so the application can work on many operating systems. Here is a list of proposed components:

- Google maps, here a student can see, where is the current location of the bus;
- An interface form to input the student's preference (arrival time at university and desired pickup point);
- ordered list of pick up points (if the user is a driver);
- data interface for communication (RESTfull service component).

Communication protocol will be based on REST service and secured by SSL accordingly. Authentication is not a critical issue, and can be realized as a login/password pair or using one of best practices for securing REST API [18].

4 Conclusion and Recommendations for Future Work

The proposed application can select a flexible bus route to minimize the walking distances as well as the total trip time considering the traffic condition and students' preferences and various schedules.

This research can help in managing the university bus service to attract more students by minimizing the walking distances, waiting time at the assembly points, and the bus trip time and length. Attracting more students for the university bus service should decrease the parking demand at the university campus and mitigate the traffic condition at the university gates as well as the surrounding road network. Furthermore, minimizing the bus trip length will help in adding extra rounds for the same line (for instance every hour) to be more suitable for the varied study schedules among students as well as for the study calendar. In addition, attracting more students for the university bus service has a potential to increase the education outcomes and to achieve the desired level of safety of transportation to and from the university.

However, the implementation of both application server and mobile client application is out of the scope of this research due to the time and budget limitations. Authors will try later to get enough budget to implement this software system.

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