OPTIMIZATION AT SERVICE VEHICLE ROUTING
AND A CASE STUDY OF ISPARTA, TURKEY

M.Fatih DEMİRAL,

İbrahim GÜNGÖR,

Kenan Oğuzhan ORUÇ

Süleyman Demirel University, TURKEY

Abstract

A typical application area of vehicle routing problem (VRP) is School Bus Routing Problem. In this problem, mainly, it is aimed to minimize total service time, length, number of vehicles operating etc. and maximize the capacity utility etc. under some constraints such as allowable time etc. The aim of this study is to construct a method that helps to organize the travel plans of students residing in an area and to apply this method at a pilot school determined under some requirements. The results of the study suggested that there are differences in the sense of the distance, time, and number of stops on the route of the service vehicles while it can be said that there is equality only in capacity utility.

Keywords: Service Vehicle, Routing, Heuristics, Optimization

Introduction

Vehicle Routing Problem (VRP) is a typical problem in operations research area which has been widely studied on by many scientists. VRP can be described as a problem that asks how a vehicle completes a traveling process while starting to travel from a center point and traveling among the other points, called as stops. VRP can be formulated easily; however, it turns to be a relatively difficult problem when the number of inputs increases. This type of problem has been widely used in daily life so that transportation and distribution costs reflect as important cost elements into companies accounting records. It is needed to use analytical models and techniques in order to decrease those costs for organizations and companies (Bodin, 1983).

Human beings meet with VRP in different areas in daily life. Some of them: various types of food and drink, clothing, heating material transportation, and garbage collection, postal

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service, personnel and student transportation. In this point of view, VRP separates into two main areas: human and freight transportation.

The aim of the study is to search for school bus routing problem (SBRP) and its solution methods, to put forward new suggestions for practical and effective solution and to apply them for a case. In the study, SBRP, its mathematical models and solution methods was investigated. Then, a mathematical model that is suitable for the case and a heuristic method for the solution were used.

1. Literature Research

Vehicle Routing and Scheduling has been a popular research area in the last three decades. VRP is a problem which finds the optimum routes that a vehicle travels in order to serve customers residing in a geographically dispersed area (Laporte et al., 1987).

It is seen that SBRP has same characteristics with VRP in several ways; however, SBRP is different from VRP because of some properties. While a typical VRP mostly deals with the freight transportation, SBRP is related with student transportation. It can be said that the other differences are to provide human satisfaction, effectiveness while traveling. Also the service transportation should be executed with the public (students, parents, school board etc.). Because of those reasons, SBRP is more complicated problem than VRP.

Savas (1978) provides three criteria for evaluating the provision of public goods and services, namely efficiency, effectiveness, and equity. Each criterion has its own unique set of considerations and objectives to satisfy yet there are clear linkages between them in terms of an overall assessment of service provision. In particular, Lee and Moore (1977) provided a linear programming model that assigns students to schools in order to achieve racial integration and to reduce school overcrowding and underutilization (Bowerman et al., 1995: 3, 4).

Most school bus routing formulations focus on formulating extra constraints and/or objectives to take some student-related factors into account. Bodin and Berman (1979), Braca et al. (1997), Desrosiers et al. (1980), add a maximum travel-time constraint for each student and/or a time window for arrival at the school. Bennett and Gazis (1972) add the total travel time of all children as an objective (Schittekat et al., 2006).

Ballou (1990) compared the "savings," "clustering," and "sweeping" vehicle routing methods. He found that the savings method could reach the solution with approximately 2 percent error to the real optimal solution, with the clustering and sweeping methods having average errors of 13 percent. The cluster method involves grouping the stops together into routes. When the cluster method was changed from determining routes by the stops' proximity to each other and introduced the vehicle capacity constraint, the error level dropped to approximately 8 percent. The sweep method involves using a rotating line to group the stops and generates routes. When the sweeping method was used in both counter-clock wise and clock-wise directions, the error level was only reduced by 1

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percent. However, even with the changes to the clustering and sweeping method, the savings method remained the best vehicle routing and scheduling of the three (Spasovic et al., 2001:2).

2. School Bus Routing Problem (SBRP)

2.1. Description and Contents of SBRP

School Bus Routing Problem (SBRP) can be specified as follows: a group of spatially distributed students must be provided with public transportation from their residencies to and from their schools. The problem is to find a series of school bus routes that ensure the service is provided equitably to all eligible students. Student eligibility for school bus transportation is determined by local school board- specific policies and is, dependent upon grade, program enrolled in, and distance of a student's residence from the school they attend. Additional restrictions are placed on the distance that students can walk from their homes to and from their stops. Although school buses serve both rural and urban areas, the differences in settlement patterns dictate that different routing systems be considered. This study considers the case of providing school bus transportation in urban areas and does not deal with school bus routing in rural areas (Bowerman et al., 1995: 2).

School bus routing is a version of the traveling salesman problem, commonly referred to the category of vehicle routing problems (VRP), either with or without time window constraints. In addition to the numerous studies that addressed the vehicle routing problem, various software methods have been developed that can utilized to minimize the operating cost. Three factors make school bus routing unique: efficiency (the total cost to run a school bus), effectiveness (how well the demand for service is satisfied) and equity (fairness of the school bus for each student). School bus routing has two separate routing issues- assigning students to bus stops and routing the buses to the bus stops (Spasovic et al., 2001: 2).

2.2. Characteristics of SBRP

The suitability of a site for being a school bus stop is influenced by characteristics such as traffic density, proximity to corners, and adjacency to public property. Because of the complicated nature of these criteria we assume that the potential bus stop sites have been selected by an analyst such as a school board transportation planner (Bowerman et al., 1995: 6).

SBRP actually involves two interrelated problems. One problem is the assignment of students to their respective bus stops and the second problem is the routing of the bus to the bus stops. Problems with these characteristics are known as a Location-Routing Problems (LRPs) (Laporte, 1988). One important characteristic of LRPs is that they are

organized into a series of layers. In this study, SBRP is organized into three layers (Bowerman et al., 1995: 6):

1- Schools
2- Bus stops
3- Students

School bus routes interact between the school and the bus stops, while the students walking to their bus stops in the morning and back home in the afternoon causes the interaction between bus stops and students. The location decisions are made in layer two (Bowerman et al., 1995: 6).

2.3. Methodology and Mathematical Formulation

This SBRP includes the following four main sub problems (Ke, 2005: 42-43):

P1: Select buses from available bus fleet (homogenous or heterogeneous)

P2: Assign eligible students to bus stops

P3: Assign bus stops to buses

P4: Determine bus routes

The SBRP considered here consists of finding an optimizing collection of some simple bus routes corresponding to buses selected from an available bus fleet such that (Ke, 2005: 44-45):

V1: each (selected) bus performs exactly one route,

V2: each route begins at school and arrives at school,

V3: each (selected) bus stop can be visited by more than one (selected) bus,

V4: the number of students on each (selected) bus must not exceed the bus capacity,

V5: the travel time of each (selected) bus must not exceed the time duration allowed

During the modeling process of this problem, a model in the literature was used as a base mathematical model (Spasovic et al., 2001: 3-5):

$$MinZ = \sum_{k=1}^{l} t_k \left(\sum_{t} d_{k,t} O_t \right) \qquad (1)$$

$$s.t. \qquad (2)$$

$$t_k \leq T_{\max}, \forall k \in L \qquad (3)$$

$$\sum_{i \in S} z_{in,k} = 1, \forall n \in N; \forall k \in L \qquad (4)$$

$$\sum_{i \in S} \sum_{j \in S} \left(x_{ij,k} \sum_{n \in N} v_n z_{in,k} \right) \leq \sum_{t} d_{k,t} * Cap_t, \forall k \in L \qquad (5)$$

$$\begin{cases} \sum_{k \in L} \sum_{j \in S} x_{ij,k} \geq 1 \\ \sum_{k \in L} \sum_{j \in S} x_{ji,k} \geq 1 \end{cases}, \forall i \in S; i \neq 0 \qquad (6)$$

$$\begin{cases} \sum_{j \in S} x_{0j,k} \geq 1 \\ \sum_{j \in S} x_{j0,k} \geq 1 \end{cases}, \forall k \in L \qquad (7) \qquad (8)$$

$$\sum_{t \in T} d_{k,t} = 1, \forall k \in L \qquad (9)$$

$$\sum_{j \in S} x_{ij,k} = \sum_{j \in S} x_{ji,k}, \forall k \in L; i \in S$$

$$bus_t = \sum_{j} d_{j,t} * x_{0j}$$

Optimal number of buses of each type denoted as **bus_t** can be calculated as above.

If $bus_t < \sum_j d_{j,t}, \forall t$, the solution is optimal. Otherwise, $bus_t = \sum_j d_{j,t}, \exists t$ (Spasovic et al., 2001: 5).

This model can be written as the following mathematical problem. Sets can be defined as follows (Spasovic et al., 2001: 3):

T: bus type available, $t \in T$

S : Bus stops with $i, j \in S$

$O(S)$: The origin and destination of bus, $0 \in O, O \subset S$

L : Bus route with $k \in L$

N : Students, $n \in N$

Variables and parameters can be defined as follows (Spasovic et al., 2001: 4):

T_{max} = Maximum time available for the bus to pick up students on a route

s_{ij} = Distance between node i and j (in meter)

t_d = Dwell time of the bus at a node (in hrs)

$z_{in,k}$ = Binary variable if a student in stop "i" travels with service "k" ($z_{in,k} \in \{0,1\}$, $\forall i \in S; n \in N; k \in K$)

$x_{ij,k} = 1$ if nodes i and j are catered consequently by bus k. ($x_{ij,k} \in \{0,1\}$, $\forall i, j \in S; k \in K$), if $\sum_j x_{ij,k} = 1$, then i is catered by bus k (or i is in bus route k).

v_n = The load of student n (2/3 if student n is an early primary grade and 1 otherwise)

$d_{k,t} = 1$ if bus route k has bus type t, 0 Otherwise ($d_{k,t} \in \{0,1\}$, $\forall k \in K; t \in T$).

O_t = Operating cost for type t bus (in YTL/hr)

Cap_t = Seat capacity for type t bus (in seats/bus)

V_t = Average speed for bus of type t (in meter per hour)

t_k = Time taken for bus k to pick up students on k^{th} bus route and drop students at node 0 is computed as,

$$t_k = \sum_{i\in S}\sum_{j\in S}\left(x_{ij,k}s_{ij} \div \sum_{t\in T}d_{k,t}V_t\right) + 2*\sum_{i\in S}\sum_{j\in S}\left(x_{ij,k}\sum_{n\in N}v_n z_{in,k}\right)*t_d, \forall k \in K$$

The operating cost of bus route k can be computed as $\left(\sum_t d_{k,t}O_t\right)$, while the seat

capacity of bus route k can be computed as $\sum_t d_{k,t}*Cap_t$.

The objective function of the problem minimizes t_k and also operating cost, O_t. Constraint (2) shows us that the service vehicles do not travel over the time allowed. Constraint (3) proves that every student at node i should be assigned to a vehicle. Constraint (4) is the capacity constraint. Constraint (5) says that each stop have to be assigned at least one school bus, (6) tells us each route should have at least one stop and (7) shows that each school bus have to be assigned only one route. According to constraint (8), it is said that there should be equality in the number of buses leaving from and arriving to school. Constraint (9) gives the optimal number of services under the bus type consideration.

3. Case Study

3.1. Problem Description

In this paper, SBRP is presented and as an application area, for the education year 2005-2006, Isparta Milli Piyango Anadolu High School was selected. The aim of the case study is to find optimal school bus routes for the selected school by using savings algorithm.

In this study, there is a feasible solution that how students are picked-up from their residencies and delivered to the school under the capacity and time constraints.

Application area, Isparta city center is divided into 37 sub-center areas with the 37 sub-center points. Sub-center points were determined, in general, at the intersections of the main roads on the city map of Isparta.

In the education year 2005-2006, there were 540 students attending to school and 255 of them took service transportation. Necessary datum for the problem was obtained with talking to school board and transportation company, *"Sertur"*. The datum is as follows:

1-Traveling time, approximately *"30-40"* minutes,

2-Velocities of vehicles, for the normal and heavy traffic, ***"30 km/h (500 m/min.) and 50 km/s (833 m/min.) "***

3-Capacity and other characteristics of vehicles (shown in Table 3.1. below)

4-Number of students at stops (shown in Table 3.2.) and

5-Addresses of students

TYPES OF VEHICLES	AVAILABLE NUMBER OF VEHICLES	CAPACITY OF VEHICLES	NUMBER OF VEHICLES USED
Minibus	4	15	4
Bus	3	18	3
Bus	2	24	2
Bus	3	26	3
Bus	3	28	1
Bus	1	30	1

Table 3.1. Characteristics of Service Vehicles Available

As it is shown in Table 3.1, although there are 16 service vehicles available, at the beginning of education year, students were assigned 14 of them. In the current situation, it can be said that there are 14 different vehicle routes being traveled by 14 service vehicles.

3.2. Heuristic Algorithm and Problem Solution

In the sense of addresses of students, residencies of them were determined and marked on the city map. Then, students were assigned to sub-center points. In Table 3.2., number of students at the stops and the neighborhood areas of those stops can be seen.

SUB-CENTER POINTS	NEIGHBORHOOD (DISTRICTS)	NUMBER OF STUDENTS
0 (SCHOOL)	Davraz	-
1	Mehmet Tönge	3
2	Çünür	1
3	Binbirevler, Batıkent	9
4	Batıkent, Muzaffer Türkeş	7
5	Muzaffer Türkeş, Zafer	6
6	Zafer, Fatih	9
7	Fatih	8
8	Batıkent, Muzaffer Türkeş, Işıkkent	5
9	Muzaffer Türkeş	6
10	Yedişehitler, Bahçelievler	9
11	Modernevler, Bahçelievler	10
12	Modernevler, Anadolu	10
13	Sanayi, Davraz	3
14	Işıkkent	6
15	Hızırbey, Gülistan	6
16	Yedişehitler, Gülistan, Bağlar	7
17	Bahçelievler, Sanayi,	10
18	Sanayi, Davraz, İstiklal	3
19	Işıkkent, Dere	4
20	Işıkkent, Hızırbey, Dere, Yenice	6
21	Hızırbey, Gülistan, Bağlar	8
22	Hızırbey, Yayla, Bağlar	10
23	Pirimehmet, Kutlubey, İstiklal	9
24	Hızırbey, Doğancı, Turan	4
25	Yayla, Pirimehmet, Çelebiler	9
26	Kepeci, Kutlubey, İstiklal	10
27	Davraz, Karaağaç	4
28	Turan, Emre, Keçeci	9
29	Kurtuluş, Sulubey, Hisar, İskender	5
30	Hisar, Halifesultan,	10
31	Gülcü, Sidre	6
32	Halifesultan, Gülevler, Ayazmana	4
33	Vatan, Davraz	6
34	Halifesultan, Ayazmana	10
35	Halıkent	10
36	Halıkent, Ayazmana	10
37	Ayazmana	3

Table 3.2. Sub-center points, neighborhoods and number of students

Time Saving Heuristic

Step 1 : Distance Matrix

After the determination of sub-center points and sub-regions in the city center of Isparta, the least distances (real road distances) between couple of points are calculated by the computerized measurement, Net CAD drawing program, and results are put in a matrix. This matrix is called *"distance matrix"* having a dimension of *"38x38"*. Secondly, a new distance matrix for the roads having heavy traffic is constructed by the same way.

Step 2 : Time Matrix

Then, through those calculations, a formula shown below is used for a new matrix construction. This matrix is called *"time matrix"* (Spasovic et al., 2001:5):

$$T_{ij} = \left(\frac{d_{1ij} - d_{2ij}}{v_1 - v_2} \right) + \left(\frac{d_{2ij}}{v_2} \right)$$

In the formula (10) above, T_{ij} is the travel time between points i and j; d_{1ij} is the distance value of i and j in the distance matrix 1, d_{2ij} is the distance value of i and j in the distance matrix 2. In denominator of formula (10), v_1 represents the normal average velocity and v_2 represents the slow average velocity.

Step 3: Time Saving Matrix

The time saved by combining any two points into one route is computed as ts_{ij}, where $ts_{ij} = T_{0i} + T_{0j} - T_{ij}$ for all i, j>0 and are the elements of the time saving matrix TS_{ij} (Spasovic et al., 2001:6; Clarke and Wright, 1964).

Step 4: Generating Routes

1-Choose the maximum positive element in Time Saving Matrix, TS_{ij}, connect nodes i and j (*i-j*), then select nodes i and j as growth nodes (potential nodes that can connect with other nodes). Calculate the total number of students, route time and length. Add "2" to the number of stops and assign the vehicle having maximum capacity to the first route.

2- Compare the total number of students calculated with the service vehicle capacity and travel time with the allowable tour time. If the service capacity is bigger than the total number of students, while the allowable tour time is bigger than the travel time; follow **"state 1":**

State 1: The next node that is going to be connected is chosen according to the maximum time saving related to the growth nodes, i and j. Then node, k, is connected to previous tour (*i -j- k* or *k -i - j*). After the connection, if the tour constructed satisfies both of the time and capacity constraint, the connection process is going to continue under the same principle. In every connection, add 1 to number of stops, sum the number of students up and calculate the total transportation time. Remove the corresponding row and column of the end notes from *"Time Saving Matrix"* .

If the total number of students calculated is bigger than the service vehicle capacity in the new tour constructed, follow **"state 2":**

State 2: Tour is completed. Turn back to number **"1"** for starting with a new tour. At this point, do not remove the corresponding row and column of the end notes from *"Time Saving Matrix"* because there is a number of students over the service capacity remaining from the last point connected in the last tour.

If the new tour constructed does not satisfy the time constraint, turn back to number **"1"** again for starting with a new tour.

3-If all the stops are included in the tours constructed, stop the algorithm.

4. RESULTS

The computer program has worked properly according to the datum entered and results are shown below:

Service Vehicle	Route	Travel Time (min.)	Route Length (meter)	Number of Stops	Number of Students	Service Capacity	Capacity Utilization(%)
1	0-5-4-3-19-20-0	18.434	14274	5	30	30	100
2	0-1-2-5-9-8-14-15-0	29.001	23919	7	28	28	100
3	0-21-24-28-22-0	11.072	8746	4	28	28	100
4	0-32-34-35-36-0	11.381	9151	4	28	28	100
5	0-25-29-31-36-37-0	12.91	10274	5	26	26	100
6	0-10-6-15-21-16-0	13.922	11120	5	26	26	100
7	0-7-10-11-17-0	10.377	8406	4	26	26	100
8	0-17-23-25-26-0	8.555	5727	4	24	24	100
9	0-17-18-27-30-33-0	12.191	9349	5	24	24	100
10	0-13-12-17-0	7.499	6008	3	15	15	100

Table 4.1. Results of the Case Study

5. Conclusion

As shown in Table 4.1., it can be concluded that:

1-In the sense of route length, time and number of stops, some of the routes are different from others. This directs us to improve the solution with another algorithm. At the result, it can be got more balanced tours in the sense of those quantities.

2-The capacity utilization is %100 and number of service vehicles operating is 10. This tells us that the result is more cost-effective than the present situation (14 vehicles are operating).

3-The differences between lengths, times, number of stops which route 1 and 2 has from other routes cause complexity in the transportation network. Therefore it will be needed to improve result in order to decrease the complexity in the network.

The varying results show us that SBRP will continue to be analyzed further. It concerns different people and has many issues inside. Therefore, the scientists, specialists, students and public should collaborate with each other to deal with this complex problem. As solution methods considered, the heuristics have to be strongly suggested for the SBRP because of the flexibility and accuracy.

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