Effective Planning of Public Transportation Systems: A Decision Support Application

Ferdi Sönmez, Nihal Yorulmaz

Abstract—Decision making on the true planning of the public transportation systems to serve potential users is a must for metropolitan areas. To take attraction of travelers to projected modes of transport, adequately fair overall travel times should be provided. In this fashion, other benefits such as lower traffic congestion, road safety and lower noise and atmospheric pollution may be earned. The congestion which comes with increasing demand of public transportation is becoming a part of our lives and making residents' life difficult. Hence, regulations should be done to reduce this congestion. To provide a constructive and balanced regulation in public transportation systems, right stations should be located in right places. In this study, it is aimed to design and implement a Decision Support System (DSS) Application to determine the optimal bus stop places for public transport in Istanbul which is one of the biggest and oldest cities in the world. Required information is gathered from IETT (Istanbul Electricity, Tram and Tunnel) Enterprises which manages all public transportation services in Istanbul Metropolitan Area. By using the most real-like values, cost assignments are made. The cost is calculated with the help of equations produced by bi-level optimization model. For this study, 300 buses, 300 drivers, 10 lines and 110 stops are used. The user cost of each station and the operator cost taken place in lines are calculated. Some components like cost, security and noise pollution are considered as significant factors affecting the solution of set covering problem which is mentioned for identifying and locating the minimum number of possible bus stops. Preliminary research and model development for this study refers to previously published article of the corresponding author. Model results are represented with the intent of decision support to the specialists on locating stops effectively.

Keywords—User cost, bi-level optimization model, decision support, operator cost, transportation.

I. INTRODUCTION

THE main purpose of this study is to make a decision support application for optimal bus stop locating and spacing which minimizes the user cost and operator cost of all the metropolitan transportation network proposed by previous studies [1]-[3] for Istanbul Metropolitan City where more than 15 million residents live. Preliminary research and model development for this study refers to Sonmez's previously published article in 2015 [2]. As a starting point social cost and operator cost are calculated, and then these costs are compared. After analysis and comparison of the user cost and operator cost between two routes, stops which should be replaced are identified. As a consequence, a need for changing

Ferdi Sonmez with Computer Engineering Department, Istanbul Arel University, Tepekent Buyukcekmece, 34537 Istanbul, Turkey (e-mail: ferdisonmez@arel.edu.tr).

Nihal Yorulmaz is with IETT Istanbul, Turkey (e-mail: nihal.yorulmaz@windowslive.com).

stop places may occur. To prevent high costs and to decide on the best stop places on the most appropriate places, estimation methods are used. Once a decision is given on the location of bus stops in a zone or area, then modifications are made to the primary conditions on which travelers in all of the network system build their modal choice decisions [1], [3], [4].

MySQL database and PHP language have been used as the development platform which was supported by gmapV3 API. HTML 5 and JScript have been used for interfaces development. Name of the DSS application is "effective planning of bus stop spacing in urban areas". Operators can use these data. Here, the main aim is to ensure comfortable and safe travel for passengers and drivers, too.

II. METHODOLOGY

The frequency of origins or destinations of trips in each zone is determined by trip generation, as a function of household demographics, land uses and other socio-economic factors [1], [5], [6]. Transportation planning [1] is reached by O-D matrix. Trip distribution step of transportation planning is modeled by using this matrix.

For this study, data are received from Information Technologies Section of IETT Enterprises. Values are used within the equations [5], [6]. The following example (Figure 1) is given for a better understanding of O-D Matrix.

	1	2	3	4	5	6
1	0	35	35	45	54	55
2	25	0	25	5	52	45
3	35	32	0	22	43	68
4	54	23	23	0	12	35
5	55	55	32	68	0	23
6	55	54	40	35	13	0
distance	600	400	200	200	600	Mt
time	300	200	100	100	300	Sn

Fig. 1 Example of an O-D Matrix

The vertical portion of the matrix gives the origination and the horizontal portion gives the destination (as shown in Fig. 1). Examination starts with the first line. Firstly, if you go from origin 1 to destination 1, distance is equal to 0. Secondly, if you go from origin 1 to destination 2, distance is 35. We process the opposite of this condition. So if you go from destination 2 to origin 1, distance is equal to 35 or if you go from destination 2 to origin 3, distance is equal to 32. It continues like this for other numbers (1-6). When we add automatically line in Excel, distance values are reached. Typically, the distance is twice that of time. Time is calculated

with this information.

A. Calculating the Operator Cost

The total cost of the kilometers covered (CK) is calculated [1], [2], [5], [7] as:

$$CK = \sum_l \sum_k L_l \, f_l CK_k \delta_{k,l} \qquad (1)$$

where L_l = length of route l (km per bus); f_l =frequency of route l (bus per hour); CK_k= unit cost per kilometer covered by bus type k (€ per km); $\delta_{k,l}$= mute variable worth 1 if bus type k is assigned to route l and 0 if not.

The cost of buses being stationary with the engine running (CR) will be depend on the time they spend at the bus stop dealing with passengers' boarding. This value is calculated [1] as:

$$CR = \left(t_{sb}/60\right) \sum_l \sum_k CR_k \delta_{k,l} Y_l \qquad (2)$$

where t_{sb} = average time for passengers getting on and off the bus (min per passenger); CR_k=unit cost per hour of bus type k standing stil with engine running (€ per hour); Y_l= journey demand on line l (passengers per hour); $\delta_{k,l}$= mute variable worth 1 if bus type k is assigned to route l and 0 if not. The personnel cost [1]-[7] (CP) is:

$$CP = Cp \sum_l \sum_k \left(tc_l/h_l\right) \qquad (3)$$

where Cp= is the unit cost per hour of the staff (€ per hour); tc_l=is the time of a round trip (min); h_l=is the headway on route l (min) = $1/f_l$; The total financial fixed cost [1, 2, 4, 7] (CF) is:

$$CF = \sum_l \sum_k \left(\left(tc_l/h_l\right)\right) . CF_k . \delta_{k,l} \qquad (4)$$

where CF_k =Unit fixed cost per hour of bus type k (€ per hour); tc_l=is the time of a round trip (min); h_l=is the headway on route l (min) = $1/f_l$; $\delta_{k,l}$= mute variable worth 1 if bus type k is assigned to route l and 0 if not.

$$\delta_{k,l} \in (0,1)$$
$$OC \le OC_0$$
$$\sum_l \left(tc_l/h_l\right) \le fls_0$$
$$F_{min} \le f_l \le F_{max} , \forall l \qquad (5)$$

where, the first constraint designate the characteristics of the binary variables $\delta_{k,l}$ and the rest of the constraints express the group of operational constraints which require to be implemented in the application, such as fleet restriction, maximum operator cost (OC), minimum and maximum allowed frequencies [1], [8], [9].Once and for all, we will calculate OC by (6):

$$OC= CK + CR+ CF+ CP \qquad (6)$$

In detail as follows:

$$OC=\sum_l \sum_k L_l \, f_l CK_k \delta_{k,l} + \left(t_{sb}/60\right)\sum_l \sum_k CR_k \delta_{k,l} Y_l +$$
$$\sum_l \sum_k \left(\left(tc_l/h_l\right)\right).CF_k.\delta_{k,l} + Cp \sum_l \sum_k \left(tc_l/h_l\right) \qquad (7)$$

III. OVERVIEW OF THE STUDY

Another aim of this study is to provide detailed trip reports that can be used by the operators, and provide the means need to find the stops that need to be optimized.
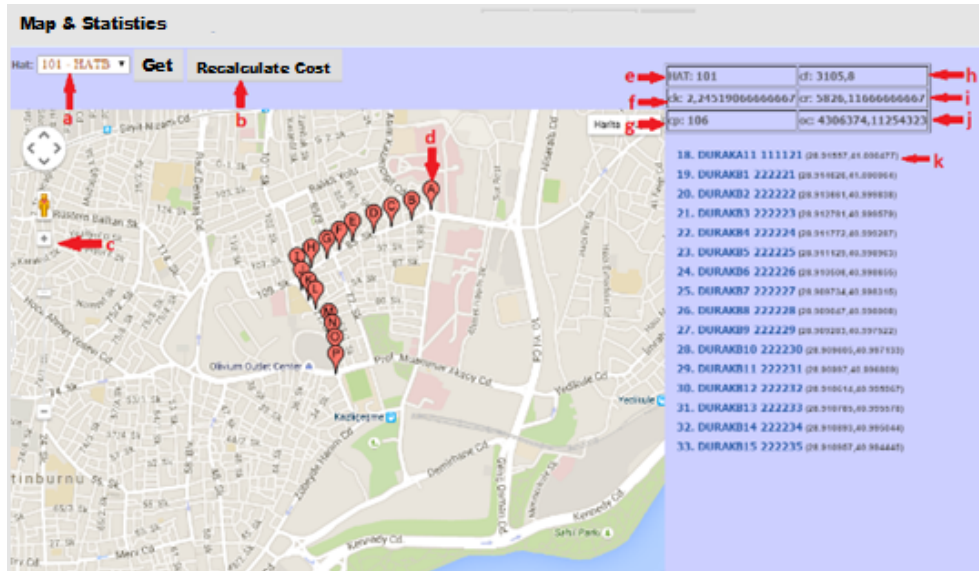

Fig. 2 Route from the origin to the destination

A. Application Perspective

Our application is independent and totally self-contained, and not a part of any other program [10]. MySQL database with PHP language is used. This work is exploited by gmapV3

API support. We also used HTML5 and jscript for development of interfaces. The parameters and variables used in the calculations [1]-[3], [5], [8]-[11] and their definitions are represented in Table I.

B. Application Functions and Variables Used

The map in Fig. 2 shows the route from the origin to the destination along with the routes and stops [11]-[13]. Details concerning the stops and the route [1], [14], [15] are shown on the right of the map.

TABLE I
VARIABLES USED IN THE APPLICATION

Name of Variable	Description
Dname	driver's name
totaltmvehic	is equal to total time in vehicle in the database
vehictm	Value of time in vehicle
waittm	is equal to value of waiting time in the database
avgwaittm	is equal to average waiting time
Stop line	Stop line
stop name	stop name
stop code	stop code
access time	in the database is equal to total access time value
TotalAccesTime	total access time
Frequency	Frequency
Line name	Line name
Line name	Line name
Line code	Line code
district	district
Manager	Every district must have a manager.
personalsost	The cost paid to person.
x coordinate	x coordinate
y coordinate	y coordinate
Linelength	length of the line.
OCost	Operator cost includes CK equation. CK equation include CK_k. CK_k= unit cost per kilometer covered by bus k (€ per hour).
avgpassenger	The average passenger number
busname	Bus name
busid	Bus ID
ctraveltime	Value of car travel time
totaltravelt	Total car travel time
orderino	Order no
tcost	Operator cost include CF equation. CF equation include CF_k. CF_k = unit fixed cost per hour of bus type k (€ per hour)
lname	driver's surname
time	Time
driver	Every bus must have at least one driver. This makes easy to find bus by identifying the driver.
DID	Driver's identification number.
tottript	The total time it takes the bus to make a complete trip.
direction	Direction (from origination to destination)

Fig. 2 is the map page of our DSS application. Here, the user first **(a)** select the line you want to know the cost of the part. Then users will want to select the button **(b)**. Calculate the operator cost of the program. When users pressed the button **(b)**, stops are ordered, as shown in Fig. 2 **(d)**. The user will be able to see the shape and then the line stops **(e)**. Name of the selected line is shown in the section **(e)**. In part **(f)** has a

CK value. CK is determined as the total cost of the bus as we know it. **(g)** Include the value of the CP section. This is the cost paid to the driver. In part **(h)** takes place in the CF which is a fixed cost. The fixed cost portion of the vehicle fuel is at the forefront. If motor runs but does not move that the cost of the car is efined as CR **(i)**. In part **(j)** seems to be the OC (Operator cost) value by which the operator is able to find the optimal line. The operator will reach it by making the change on the stops. In the section **(k)** the name of the stop code and coordinate information are shown. By using section **(c)** it is possible to zoom out the map like you want the user part will be able to clearly see the area which is the choice of users.

IV. DESCRIPTION OF THE PROPOSED SYSTEM

In this section a background for the requirements is given for the consumption of the customer and a description of the programs functions and interface is provided**.** Our application is independent and totally self-contained, and not a part of any other program. It is made as an alternative for other programs with the same purposes. It is used to specify routes for small and large transportation companies.

The program will require password to login. At the top of the interface there will be bar, in this bar the user can insert the destination and origin of a trip and right next to them the trip's OC and UC will be shown. Below there will be a map showing the route from the origin to the destination along with the routes stops. Details concerning the stops and the route will be shown on the right of the map.

A. Interface Design

We start the program by first logging in from the log-in screen. The *user name* and *password* area are to be filled and they will be compared with the ones that were entered into the database before and then the user will be logged into the application main page in Fig. 3. A table with the name *user* is made in the database with the following elements in Table II:

TABLE I
USER ELEMENTS

Name of Variable	Description
Id	ID is the primary key and will be identically and automatically set. By this way, there will not be any duplications.
Authentication	Authentication Credentials
Username	Username of auhorized user
Password	Password of auhorized user
Email	E-mail of the auhorized user

The first page that a user will see after logging in is the Main Page. Through this page one can access to the Stop Adding & Editing Page to insert new stop data or to edit those recorded data. The areas at that page marked are explained. User will see *(2) add stop* in the source data area. When user select *add stop*, the page is opened in central area. After pressing add stop from the source data tab, the program will be as shown in the image in Figure 3 with areas; (***a***) *Stop Code*, (***b***) *Stop Name*, *x* (***c***) *latitude* and *y* (***d***) *longitude* to be filled.

Fig. 3 Bus Adding and Editing Page

Fig. 4 Line Hours Adding and Editing Page

When a new stop is added the operator will fill these areas and then once (*f*) *save* is pressed the data will be entered into the database. (*e*) *clear* is used to clear all the data entered. Right below it is the settings area for the registered stops. The user can see all the data about the stops that have been entered and saved before. It would be enough to press on the (*g*) *Delete* button to remove a stop. *Print* will save it to excel and *delete all* will erase everything to make it easier for the user.

A table by the name *stop* is made in the database with the following elements: *StopCode* is defined as the primary key. Every stop will thus have a unique *StopCode*. These will be given by the operator himself. CoordinateX and CoordinateY are the coordinates taken by the help of Google maps. Next is *Add Line Times* in Figure 6. When user clicks *ad line* (**3**) button, the page is opened in the main page area.

In Fig. 4, we have (**a**) *Line Code*, (**b**) *Total O-D minutes* and (**c**) *direction*. Information wanted by the line operator will be available here. A table by the name *line hours* is made in the database with the following elements in Table III.

Add Route page is area that user will edit route in Figure 5. User can see and press all data about route that user has. We will press data that are calculated as the user cost equation data.

User cost equation that are used all variables were recorded in the database other names. This variable will be described in Table III. A table by the name route elements is made in the database with the following elements listed in Table III.

Coefficient is assigned for every stop according to passenger attractiveness [1], [2], [5]. For instance; if the waiting time of the bus stop is very less than other bus stop, this bus stop is more attractiveness than other. Hence, if stop is more attractive than other, we assign small number. Passenger choose bus stop which is short time for going from place to place. The best bus stop value is small according to other. As each page, user can see recorded data. Also, user edits all data as follows in Fig. 6.

Fig. 5 Route Adding and Editing Page

TABLE III
ROUTE ELEMENTS

Name of variable	Description
LineCode	Line code
LineName	Line name
StopLine	Stop line
StopCode	Stop code
Direction	Direction
OrderNo	Order no
XCoordinate	x coordinate
YCoordinate	y coordinate
M	M is equal to Meter
Time	Time
AvgPasNum	The average passenger number
WaitingTime	The waiting time
WaitTime	Wait Time
Access	Access
ValueAccessTtime	Value of access time
VehicleTime	Vehicle Time (total in vehicle time)
ValueInVehicleTime	Value of in vehicle time
TotalTransferTime	Total transfer time
ValueTransferTime	Value of transfer time
TotalCarTravelTime	Total car travel time
ValueCarTravelTime	Value of car travel time
Frequency	Frequency

We will see add bus (5). When it is clicked at add bus (5) part, the editing page will appear as shown in Fig. 7. A table by the name bus is made in the database with the following elements shown in Table IV.

As it seen on the page; when it is clicked at part add line (6), the editing page will appear as shown in Fig. 8. A table by the name line is made in the database with the following elements in Table IV.

Editing Recorded Line: (h). All record lines will be shown in order at this part according to their line code. Editing also can be done in this page in Fig. 8.

The last part in the source data is the observation form **(7)** in Fig. 9. When operator clicked this part, a page appears. At this part, is will be kept the records of employees. So, a table called "form" is created in the database.

Editing Recorded Forms: **(i)**. All recorded lines will be shown in order at this part according to their line code. Editing also can be done in this page in Fig. 9.

TABLE IV
LINE AND BUS ELEMENTS

Name of variable	Description
Linename	A unique Line name
Linecode	A unique Line code
District	District
Operator	Operator
Recorded Bus Editing	recorded bus editing
M	Meter
Total Operator Cost	total operator cost
Bus Name	bus name
Bus ID	Bus ID
Total vehicle travel COST	Total vehicle travel COST
Driver	Driver
Total time	Total O-D time (in minutes).
Direction	Direction to destination

Users **(a)** part will include the information both who is going to use the program and how in Fig. 10. When we clicked this part, user add and edit page will appear which is shown. According to this page, **(b)** section has user name and surname. **(c)** Section has the e-mail address of the user. In any forgotten password case, new password will be sent to user's mail address via e- mail. **(d)** Section includes username. This section appears after first entering to the program and it will be at the login screen including name section. **(e)** Program will be accessed with username and password. **(f)** Password again. **(g)** Section includes the authorization levels. The authorization

levels consist of three categories in Table V.

Fig. 6 Editing Recorded Route

Fig. 7 Bus Adding and Editing Page

Fig. 8 Line Adding and Editing Page

Fig. 9 Employee Observation Form

Fig. 10 Users Page

TABLE V
AUTHORIZATION LEVELS

Name of Variable	Description
User	User only has to authorization of displaying.
Editor	Editor can update, cannot enter new record, cannot delete a record.
Admin	Admin has to authorization of adding, updating and easing records

Areas at the top will give an ease of use to find the recorded data. Firstly, we look at stop button **(a)** as in Fig. 11.

In this section, user will write demand *stop code* in the **(e)** area. Later user press stop button. When user press the stop button, stop adding and editing page will open center area. All record data connected with writing stop code will open like **(f)** in Figure 11. User enters line code to above text area and later clicks the line button. Line adding and editing page is opened. Information belonging to line will be shown at the end of the page.

User enters stop code in the text box **(e)** and press route button**(c)** for knowledgeable with route. Later route adding and editing page is opened. Registered route has the same stop code.

User enter bus id that want to search in the text box **(e)** and press bus button **(d)** in Fig. 12. When user presses bus button, the bus adding and editing page is shown. Recorded busses which have the same bus id **(f)** are shown on the bottom of the page.

V. CONCLUSION

O-D traffic demand matrix is an important source of data for the equilibrium assignment [1]-[2]-[16]. So, O-D traffic demands is important for a reliable estimate of the calculations we make. In this study, the traffic calculation according to the assignments made, and as a result is provided to detect the most optimal stop. Over the years, socio-economic factors that will be due to the change and improvement in the data obtained, the developed application can be made with the update of the data is provided renewed at any moment.

For this study, data of 300 buses, 300 drivers, 10 lines and 110 stops are used. The values that occur at the stops were examined individually. Graphs were obtained with from occurring values. Making comparisons are provided between

two lines. Separate cost accounts for the cost of the operator are reviewed. By the way, cost functions are affected by the volume of traffic.

Fig. 11 Stop Button

Fig. 12 Bus Button

As a result of the equations that are used on the value of the cost of an operator has been reached. These values were compared with all lines comparison results are shown in the graphs. Even the cost of any changes affecting the whole of the line was calculated. We want to optimize costs that occur even after the changes we made a comparison was made of the cost of old.

Proposed system is well suited with previously proposed methods and assignment of traffic assignment which is done by raising the calculated travel time works [17]. The calculation of user cost values that occurred at each stop is a subject of another study. In this context, it is planned to perform this calculation and show these values for each bus stop. Being able to observe stops on their cost values is an important concern for passengers. In this context, it is planned to perform calculation of both user and operator costs in a software application in a future work.

REFERENCES

[1] Ibeas, Á., Alonso, B., Sainz, O. Optimizing Bus Stop Spacing in Urban Areas. Transportation Research Part E, 46, pp. 446-458, 2010.

[2] Sönmez, F. (2015). Optimizing Bus Lines in Urban Public Transportation by Cost and Trip Calculation Methods: A Software Model Design. International Journal of Electronics, Mechanical and Mechatronics Engineering, 5(3), pp.969-977, Doi: 10.17932/ IAU.IJEMME.m.21460604.2015.5/ 3.969-977

[3] Bowerman, G., Hall, B., Calamai, P. A multi-objective optimization approach to school bus routing problems. Transportation Research Part A 28 (5), pp.107–123, 1995.

[4] Ceder, A., Wilson, N.H.M. Bus network design. Transportation Research Part B 20, pp.331–334, 1986.

[5] Ceder, A., Prashker, J.N., Stern, J.I. An algorithm to evaluate public transportation for minimizing passenger walking distance. Applied Mathematical Modeling, 7(1), pp.19-24, 1983.

[6] Ceder, A. Bus frequency determination using passenger count data. Transportation Research Part A, 18, pp.439–453, 1984.

[7] Chriqui, C., Robilland, P. Common bus lines. Transportation Science, 9, pp.115–121, 1975.

[8] De Cea, J., Fernandez, J.E. Transit assignment for congested public transport systems: an equilibrium model. Transportation Science, 27, pp.133–147, 1993.

[9] dell'Olio, L., Ibeas, A., Moura, J.L. A bi-level mathematical programming model to locate bus stops and optimize frequencies. Journal of Transportation Research Board, 1971, pp. 23–31, 2006.

[10] Bard, J.F. Practical Bilevel Programming: Algorithms and Applications. Kluwer Academic Publishers, Dordrecht., 1998.

[11] Gleason, J.M. Set covering approach to the location of Express bus stops. Omega 3, 605-608, 1973.

[12] Kraft, W.H., Boardman T.J. Location of bus stops. Journal of tramsportation engineering 98 (TE1), pp.103-116, 1972.

[13] Räsänen, M. Functionality of a bus stop at exit or merging lanes and its impact on driver bahavior. Traffic Engineering and Control, 47 (1), pp. 29-32, 2006.

[14] Üçer, F. Ulusal karayolu sisteminin ağ güvenilirliği yaklaşımı ile incelenmesi. PhD Thesis. Balıkesir University, Civil Engineering, 2009.

[15] Cea, J.D., Fernández, J.E., Dekock, V., Soto, A. Solving network equilibrium problems on multimodal urban transportation networks with multiple user classes. Transport Reviews, 25(3), pp.293-317, 2005.

[16] Farahani, R.Z., Miandoabchi, E., Szeto, W.Y., Rashidi, H. A review of urban transportation network design problems, European Journal of Operational Research, 229, 2, pp.281-302, 2013.

[17] Altinkaya, M., & Zontul, M. (2013). Urban bus arrival time prediction: A review of computational models. International Journal of Recent Technology and Engineering (IJRTE), 2(4), 164-169.