Optimizing Bus Lines in Urban Public Transportation by Cost and Trip Calculation Methods: A Software Model Design

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Abstract

Planning of a public transport system in an ordered way is the key which offers potential users a mode of transport. To attract travelers from other modes of transport, sufficiently attractive overall journey times must be provided, so reducing traffic congestion and obtaining delivered benefits like road safety and lower atmospheric and noise pollution. The congestion that close with increasing demand is becoming a part of our lives and it is complicating our lives. Some work is done to reduce the traffic congestion. If we want to provide an efficient and balanced layout in public transport system, we must place the right stop at the right places. Hence, we consider some components like cost, security, noise pollution, etc. In this study, it is aimed to solve a set covering problem for locating the smallest number possible of bus stops.

Keywords: *Bus Stop Spacing, Bi-Level Optimization Model, Trip Demand, O-D Matrix.*

1. Introduction

Purpose of this work is to make an optimal bus stop location and spacing model which minimizes the operator cost of all the transport system, examine the equilibrium travel costs by installing the route under travel costs among the studied O-D (Origin–Destination Matrix) pairs, stated by the travel distribution [1, 2]. Firstly, we calculate operator cost, later we will compare these costs. We will determine analysis of the operator cost between two routes and identify routes that cause the most cost [1, 2, 3]. Our focus will be on optimizing these routes. If we need to change stops, we will change stop places. We need to put the best stops on the most appropriate places and to solve this problem we use the estimation method [2, 3]. Once a decision is made to modify the

location of bus stops in an area then changes will be made to the initial conditions [1] on which travelers in all the system base their modal choice decision.

Operators can use these data. It is aimed to ensure traveling comfortably [4, 5] and safe movement for passengers from a place to another.

2. Methodology

Trip generation determines the frequency of origins or destinations of trips in each zone by trip purpose, as a function of land uses and

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household demographics, and other socio-economic factors [1, 4, 5]. Transportation planning [1] is reached by O-D matrix. Trip distrubtion step of transportation planning is done modelling by these using matrix.

An illustration of the O-D matrix is given in Figure 1.

Origin \ Destination	1	2	3	Z
1	T_{11}	T_{12}	T_{13}	T_{1Z}
2	T_{21}			
3	T_{31}			
Z	T_{Z1}			T_{ZZ}

Figure 1: *An Illustration of the O-D Matrix (Üçer, 2009)*

Here, T_{ij} = Trips from origin i to destination j. For example; if the passanger comes from origin 1 to destination i, trip will be a T_{11}. In this project O-D matrix values are used. Generally, O-D matrix values are reached with survey [4,5]. But for this project data is received from IETT (General Directorate of Istanbul Electricity, Tramway and Tunnel) Information Technologies Section. Values are used within the equations. The following example is given for a better undertanding of O-D Matrix.

O-D	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	224	199	155	175	174	226
Time	448	398	310	350	348	452

Figure 2: *Example of an O-D Matrix*

The vertical portion of the matrix show the origin and the destination of the matrix show down time in Figure 2. 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 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.
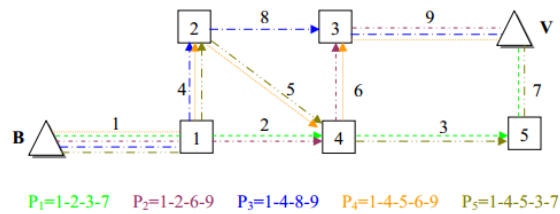

$P_1=1-2-3-7$ $P_2=1-2-6-9$ $P_3=1-4-8-9$ $P_4=1-4-5-6-9$ $P_5=1-4-5-3-7$

Figure 3: *Examples of Network (Üçer, 2009)*

Figure 3 shows the cost between routes. For instance, the green route is preferred then the cost is 13. P1, P2, P3, P4, P5 are calculated. This figure allows to find the shortest distance.

2.1. Calculating the Operator Cost

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

$$CK = \sum_l \sum_k L_l f_l CK_k \delta_{k,l}$$

(2)

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 passenger. This value is calculated [1] as:

$$CR = \left(t_{sb}/60\right) \sum_l \sum_k CR_k \delta_{k,l} Y_l$$
(3)

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 :

$$CP = Cp \sum_l \sum_k \left(tc_l/h_l\right)$$
(4)

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:

$$CF = \sum_l \sum_k \left(\left(tc_l/h_l\right).CF_k.\delta_{k,l}\right)$$
(5)

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.

$\delta_{k,l} \in (0,1)$

$$OC \leq OC_0$$
$$\sum_l \left(tc_l/h_l\right) \leq fls_0$$
$$F_{min} \leq f_l \leq F_{max}, \forall l$$

Where, the first constraint defines the characteristics of the binary variables $\delta_{k,l}$ and the rest of the constraints represent the group of operational constraints which need to be implemented in the model, such as maximum operator cost (OC), fleet restriction, and maximum and minimum allowed frequencies [1, 7, 8].

Once and for all, we will calculate OC by the equation below;

OC= CK + CR+ CF+ CP
(6)

In detail, be showed as follows.

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

3. Overview Of The Study
The general aim of this article 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.

3.1 Model Perspective
Our model is independent and totally self-contained, and not a part of any other program [9]. MySQL database with PHP language is used. This work is exploited by gmapV3 API support. We also used HTML 5 and jscript for interfaces development. The parameters and variables used in the calculations [1, 2, 4, 7, 8, 9, 10] and their definitions are shown in Table 1.

3.2 Model Functions and Variables Used

Below there is a map (Figure 4) showing the route from the origin to the destination along with the routes stops [10, 11, 12]. Details concerning the stops and the route [1, 13, 14] will be shown on the right of the map.

Table 1 : Variables Used in the Model

| 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
total access time	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	The data will be used in the operator cost calculation. Operator cost includes CK equation. CK equation include CK_k. CK_k= unit cost per
	kilometer covered by bus k (t per hour). İt is thought as fuel.
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	The data will be used the operator cost calculation. Operator cost include CF equation. CF equation include CF_k. CF_k = unit fixed cost per hour of bus type k (t per hour)
lname	driver's surname
time	Time
driver	Every bus must have 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 do a complete trip.
direction	Direction (from origination to destination)
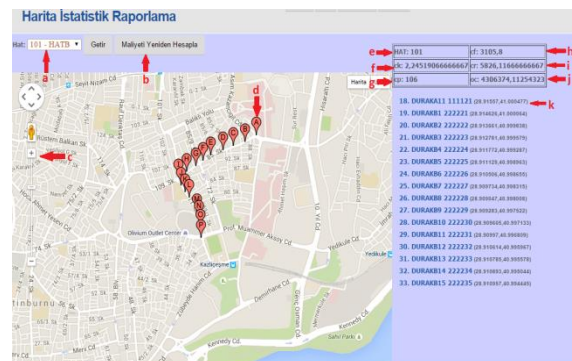
Figure 4: Map Page

Figure 4 is the map page of our software model. 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, such as in figure (**d**). The user will be able to see the shape and then the line stops (**e**). The name of the line that selected 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 the CR motor runs but does not move occurring is the cost of the car (**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 choice of users.

## 4. Model Results

CF values of all line according to bus as follows. In Figure 5 shows that total fixed cost for each bus. We see that HAT A has the maximum cost, as shown in the graph. The user who wants to look at events in terms of fixed costs in HAT A, the user should change on the HAT A.
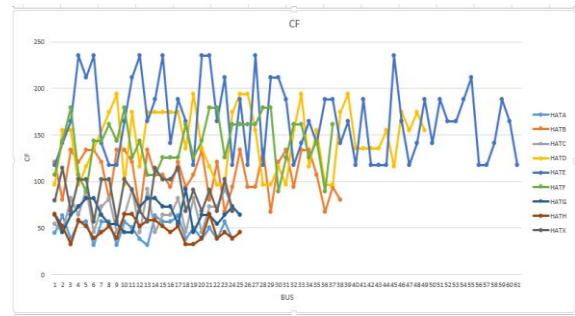

Figure 5: The Total Financial Fixed Cost Graph

CK altering graph of all line according to bus as follows in Figure 6. This graph show total cost of the kilometers covered.
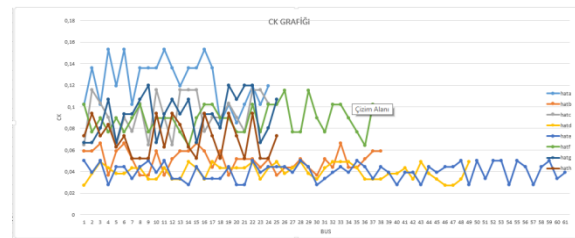

Figure 6: *Total Cost of the Kilometers Covered Graph*

CR altering graph of all line according to bus as follows. CR is unit cost per hour of bus type k standing still with engine running (₺ per hour), Figure 7 show us CR graph. Here, we take into account part that is time for passengers getting on and off the bus (minutes per passenger). Numbers express the bus name. Horizontal line express the CR values according to each line.
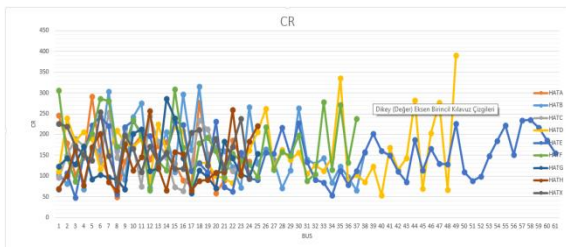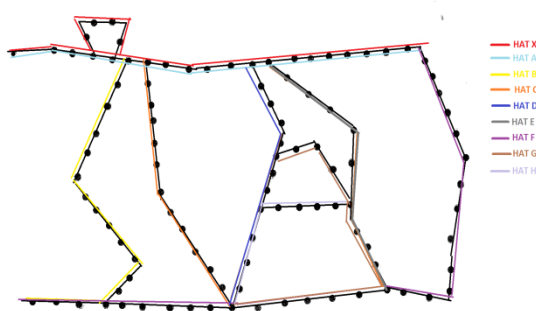
Figure 7: *The Cost of Bus Standing Still with Engine Running Graph*

CP altering graph of all line according to bus as follows. In Figure 8, it is defined the paid to the driver that the total cost calculation is performed and the chart has been drawn.
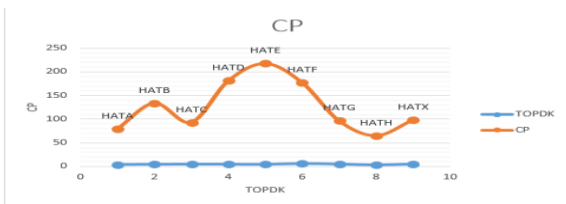
Figure 8: *The Personel Cost Graph*

4.2 Comparison of the Results

***Figure 9:*** *Diferent Line Variations*

The above lines were investigated in Figure 9. With different colors from each other, each line has its own unique costs were calculated.

As a result of this calculation, the following charts reached.

Here we will consider Figure 9. We will examine by comparing HAT X (Line X) and HAT A (Line A). Normally the HAT X is our route (Figure 9). We removed some stops on the HAT X. When we removed stops from HAT X, HAT A is our new line. Then cost account made for the HAT A. HAT A and HAT X the only difference from occurring also are the stops. We just pulled the stops from HAT X. Other variables remained the same. Stops were used as a variable. The charts below includes the reached results of our investigations.

Software model compares CF value that is between HAT A and HAT X, as follows; (Figure 10)

Fixed costs that is also occurring on the HAT X are more likely to HAT A. The numbers in the horizontal column is buses. Fixed costs are as shown in vertical space. According to the fixed cost, a user must choose HAT A. The goal of our model is to find the line which has the lowest cost. Here, at HAT A we saw lower cost.
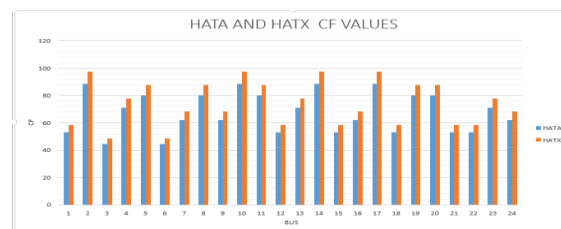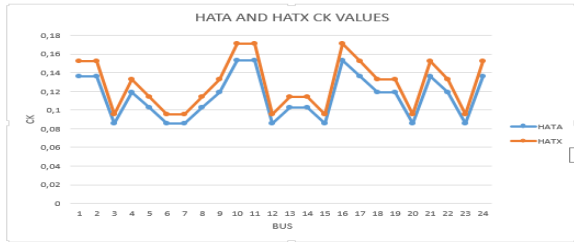

Figure 10: *Comparison the Total Financial Fixed Cost Graph*

CK value graph that is in the between HAT A and HAT X, as follows in Figure 11. This graph show us total bus costs. The numbers from 1 to 24 refers to the buses on here.
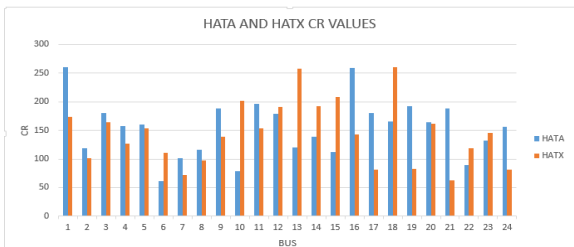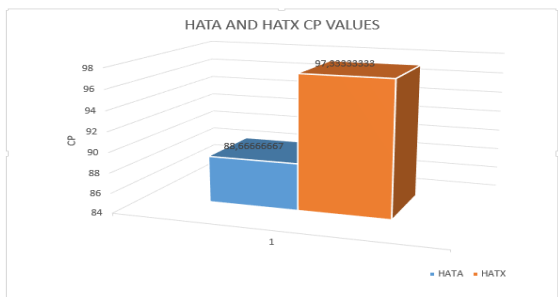
According to graph, HAT X has the most cost.

Figure 11: *Comparison Total Cost of the Kilometers Covered Graph*

CR value graph that is in the between HAT A and HAT X (Figure 12).

Figure 12: *Comparison the Cost of Bus Standing Still with Engine Running Graph*

Figure 13 shows the variation of the cost paid to the driver. The difference between the two lines as seen below.

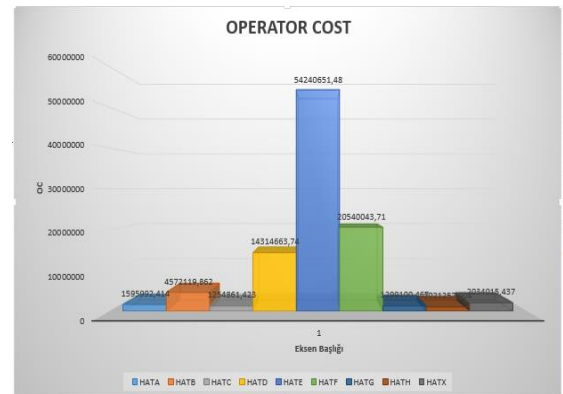**Figure 13:** *Comparison the Personel Cost Graph*

We come through as follows with information mentioned above. CP-CK-CR-CF graph; also refers to the lines from 1 to 9 in Figure 14.
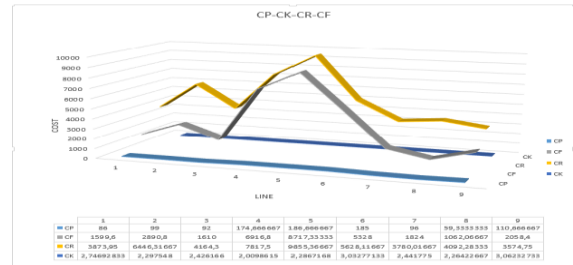
Figure 14: *Comparison all Cost Graph*

Each number corresponds to one line. Here, the values are examined individually in a cumulative manner.

Result of an operator cost graph as follow in Figure 15.

Figure 15: *Operator Cost Graph*

As a result, we can see all values above graph. The graph examine changing cost values. Operator will compare all values about graph in Figure 15, later will decide line where user want to optimize [12, 14, 15]. HAT A and HAT X is compared by above graph. User can see all data. For example we compare HAT A and HAT X lines, we see that operator cost of HAT A is 1595992,41

and HAT X is 20340115,43. Operator decides [14, 15] routes and stops by looking at these results.

5. Conclusion

O-D traffic demand matrix is an important source of data for the equilibrium assignment. 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 model can be made with the update of the data is provided renewed at any moment.

Our study include 283 drivers, 8 lines, 110 stops and 283 buses. The values that occurr 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.

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.

In traffic assignment, which is done by raising the calculated travel time from the proposed method works well with each other,

they left a very big difference, therefore it has been determined that.

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 model in a future work.

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