THE INTERNATIONAL JOURNAL OF BUSINESS & MANAGEMENT

A Study on Optimization of Dead Kilometer: Case of Istanbul Metrobus (BRT) System

Burak SEVIM
BRT Manager, Department of BRT, The General Directorate of IETT, Istanbul, Turkey
Dr. Mehmet Nuri INEL
Assistant Professor, Department of Quantitative Methods, Marmara University, Istanbul, Turkey

Abstract:
Fuel cost is one of the biggest expense item in urban wheeled public transport. Aside from the fuel being very expensive, expenses created by movements without passengers (journeys from the depot to the beginning of the line/the end of the line, and vice versa), and the presence of expenses referred to as dead kilometer in the literature are important factors that result in fuel costs to be high.
According to the data obtained from General Directorate of IETT Operations, dead kilometers comprise a significant portion of the kilometers that are realized. With this study, it has been aimed to reduce dead kilometers by making changes in the line-depot matching by using optimization techniques. Scope of the study is the lines and depots under the execution, management and control of General Directorate of IETT Operations that provide public transport service on the BRT (Bus Rapit Transit) system.

Keywords: *Assignment, BRT, Depot, Route, IETT, Optimization, Dead Kilometer*

1. Introduction

This study aims the optimization of the costs of the buses in the Metrobus system under the management and supervision of the General Directorate of IETT due to the distance between the garage - line start point/line end point or line start point/line end point – garage covered without any passengers and called “dead kilometer” in the literature. These costs directly affect fuel costs, which is one of the largest items of operating costs. At the same time, an extra benefit of the study is its environmental aspect since each extra kilometer covered directly affects the amount of CO_2 released into the air.
Buses goes at the beginning of the day from the garages to the A and B points, which are called as the line start point and line end point, and returns to the related garages from the A or B points at the end of the day. Such travel of the busses causes a dead kilometer. 499 buses are running on 7 different lines from 4 different garages on the BRT (Bus Rapid Transit-Metrobus) system in Istanbul. In this study, the linear programming method was used to optimize the dead kilometer originating from travels without passengers between the garages and points A-B. The model was designed by adding to the minimization objective function the following constraints; capacity constraints of garages, constraints of starting bus numbers at points A and B, constraints on assumption of “not sending busses from the extreme garages to A and B points located at the extreme points”, constraints on assumption of “the number of buses leaving the garage in the morning equals to the number of buses returning the garage in the evening” with respect to busses serving in the operation types called “entering the garage during the day”, “split duty” and “depot changed duty”.
Before moving on to the methods and results of the study, it would be useful to review the local and global scientific literature studies that have already been done in this regard and minimize the dead kilometer and fuel costs. Nasiboglu, Eliiyi, Ozkilcik and Kuvvetli (2011), in their work for Izmir, have built their models on four different scenarios. First scenario is company indifferent - garage capacity unlimited, second scenario is company indifferent -garage capacity limited, third scenario is company separated - garage capacity unlimited, and the fourth scenario is company separated - garage capacity limited. In the result of their construction, there is a decrease by % 31.4, 5.287 km per day and 964.878 liters of fuel per year in the first scenario. These values are the total values of the two transportation authorities of Izmir city, ESHOT and Izulas, as the first scenario is company-indifferent. There is a decrease by % 21.7, 3.652 km per day and 666.490 liters of fuel per year in the second scenario. These values reflect the total reduction in figures of both companies too. In the third scenario, there is a decrease by % 20.4, 2.608 km per day and 475.960 liters of fuel per year for ESHOT and by % 10, 406 km per day and 74.095 liters of fuel per year for Izulas. In the last scenario, there is a decrease by % 8.3, 1.057 km per day and 192.903 liters of fuel per year for ESHOT and by % 6.5, 265 km per day and 48.363 liters of fuel per year for Izulas. In a study by Djiba, Balde, Ndiaye, Faye and Seck (2012), a daily saving of 2.613,1 km, corresponding to approximately € 78.393 per month was achieved by the optimal distribution of garage-line buses between the Thiaroye and Ouakam garages. Kepaptsoglou, Karlaftis and Bitsikas (2009) have developed a decision support system to assign buses to the garage to keep the dead kilometer at the optimum level and they tested it on the public transport in Athens. In their study, Agrawal and Dhingra (1989)

focused mostly on increasing the garage capacity. In this context, they tried to decide on the optimal number of buses to be parked in the night garages and the optimal distribution of these buses considering the distances between the garages and the line heads. Mahadikar, Mulangi and Sitharam (2015), in the model they developed for BMTC, reduced the dead kilometer of garages 7, 13, 18, 25 and 28 from 3.573,9 kilometer to 2.381,9 kilometers to gain 1.192 km per day. In the current case, the optimality was ensured as the daily dead kilometer of garage number 7 was decreased from 365,1 kilometer to 123 kilometer, the dead kilometer of garage 13 was decreased from 1.115,9 kilometer to 927,4 kilometer, the dead kilometer of garage 25 was decreased from 1.048 kilometers to 657,7 kilometers, the dead kilometer of garage 28 was decreased from 818,9 kilometer to 364,5 kilometers while the dead kilometer of garage 18 was increased from 226 kilometers to 309,3 kilometers. Uyeno and Willoughby (1995) tried to decide the locations and capacities of garages with the integer linear programming model they developed for the Vancouver Regional Transit System company in Canada. On the basis of the work done, the operating costs at the optimal level have been reduced by 3,77%, earning $ 560.000 per year. Besides, there is a decrease by 10,73 % in costs due to dead kilometer. Waters, Wirasinghe, Babalola and Marion (1986) have developed a model that allows new garages to be set up at optimal locations to minimize the cost of dead kilometer. In a line-garage assignment model with 13 garages of MDK company in India, Sridharan (1991) reduced the dead kilometer from 4.909,6 km to 3.984 km by %18,84 reduction of dead kilometer. Van der Perre and Van Oudheusden (1996) achieved a 42% savings in non-service costs as a result of hierarchical approach optimization with data from a large bus company named BMTA in Bangkok. This savings is equivalent to 10.431.000 kilometers per year. Sharma and Prakarash (1986) have developed quantitative methods related to the optimal plan for the number of buses to be parked in night garages and to go line start and end points from these garages, considering their capacities at optimal level. Prakash and Saini (1989) conducted a study to determine the optimal location of a new garage according to the starting points of the lines and to determine how much free capacity should remain in each garage after the new garage was built. In the result of Willoughby's model for bus assignment according to garage locations in Vancouver's public transport system in Canada, annual costs due to dead kilometer (2001) decreased from $ 14.528.000 to $ 12.772.845 thanks to cost-minimizing approaches. In his work, he has reduced the dead kilometer by installing a new garage Vancouver from 5 candidate garages. If we consider these installation costs, our annual earnings fall to about $ 700.000. Willoughby and Uyeno (2001) tried to find the optimum status by working on an intuitive method to get buses connected to the lines out of the same garage and then distributing them to alternative garages taking into account the capacity constraints of the garages. Pepin, Desaulniers, Hertz and Huisman (2006) focused on five intuitive methods producing quality and fast solutions for public transport systems with multiple garages. Prakash, Balaji and Tuteja (1999) considered, regardless of priority, the optimum number of buses to park in garages according to the starting points of the lines and at which level garages were left with vacant capacity.

2. Current Status

The introductory part of the study describes the purpose of the application and includes the literature searches. In this section, the method, field and steps of the application will be explained.

This study, similar to the studies made locally and globally in relation to the optimization of dead kilometer, deals with the BRT system of Istanbul and it will determine which garages (of the four garages at Edirnekapi, Avcilar, Beylikduzu and Hasanpasa where only the busses serving on BRT lines are parked) should the 499 buses operating in 7 BRT lines depart from to minimize the total dead kilometer. The mileage gained in the result of such study will be interpreted in terms of fuel costs and CO_2 emissions into the air

The distribution of the buses that provide public transportation service in 7 lines mentioned above according to their lines and operation types are given in Table 1 below.

Line Code	Name of Line	Splity duty	Depot changed duty	Normal	Total
34	Avcilar-Zincirlikuyu	34	0	21	**55**
34A	Cevizlibag-Sogutlucesme	0	0	0	**0**
34AS	Avcilar-Sogutlucesme	42	28	82	**152**
34BZ	Beylikduzu-Zincirlikuyu	23	14	116	**153**
34C	Beylikduzu-Cevizlibag	57	0	13	**70**
34G	Beylikduzu-Sogutlucesme	0	0	15	**15**
34Z	Zincirlikuyu-Sogutlucesme	43	0	11	54
Total		**199**	**42**	**258**	**499**

Table 1: Number of Busses in BRT Lines as per Their Operation Type

As one can see there are 3 types of operation. These are; splity duty, depot changed duty and normal operation types. In splity duty operation, a bus is used by a driver only at peak times. The dead kilometer of this bus operating splity duty is the total of;

- Distance between the garage and start point of the line in the morning,
- The distance between the point where it made the last trip and the garage where it is connected in the middle of the day (time period which is low compared to peak hours in terms of number of passengers)
- The distance traveled, after the end of the rest period, between the garage where it rests and the respective starting point (A or B point) of the line to perform the evening operation in the evening,
- At the end of the day, after the driver finishes his shift, the distance the bus travels without any passengers from the last point of the line to the garage.

In splity duty operation, there are dead kilometers on four levels.

A bus is operated by two drivers in the normal operation type. The first driver takes the bus out of garage in the morning and operates it all during his shift. At the end of the shift, he hands over the bus to the second driver and the second driver operates it all during his shift. He brings the bus will to the garage from the end of the line after he completes the last scheduled trip. There are dead kilometers on two levels here.

Depot changed duty operation system can be thought as a combination of splity duty and normal operation types. A bus is operated by two drivers in this operation type very much like the normal operation type. However, what makes the depot changed duty operation system different from the "normal" operation type and similar the splity duty operation type is that the second driver takes over the bus not on the line but from the garage where the bus is connected to. Once the first driver completes his shift, he brings the bus to the garage. The second driver goes to the line by picking the bus up from the garage on the time scheduled for him. He brings the bus will to the garage from the end of the line after he completes his shift. There are dead kilometers on four levels in this mode of operation.

In the current structure, buses can be provided to every line from every garage. For instance, the buses depart from all the 4 garages for the line number 34BZ. Table 2 contains information on how many buses are taken from each garage for each and every line. Here, what is notable at first glance is that each line is specified twice in splity duty and depot changed duty operation types, one being morning and the other evening. The reason is that, when calculating the dead kilometer at the present and optimal level, we count the operating buses entering the garage in the middle of the day as a separate line, one in the morning and the other in the evening. However, although these buses are displayed separately, they are the same buses. Therefore, the fact that the total sum number of buses seeming to be duplicate in lines splity duty and depot changed duty operation modes is equal explains this situation. As already mentioned above, there are 4 levels of dead kilometer in splity duty and depot changed duty operation modes and 2 levels of dead kilometer in normal operation mode. Due to the duplicate, here, splity duty and depot changed duty operation modes are divided into two and the reduction of dead kilometer dead kilometer is made in two levels. Such method of tabling aims to facilitate the minimization problem. There is also an index number for each situation that appears as a line in Table 2.

For example, in the current situation as seen in Table 2, of the busses operating splity duty mode in the morning on 34BZ line in number 7, 4 buses go from Edirnekapi garage to point A, 1 from Edirnekapi garage to point B, 5 from Avcilar garage to point A, 9 from Beylikduzu garage to point A and 4 of them from Hasanpasa garage to point B. Beylikduzu is point A and Zincirlikuyu is point B on the 34BZ line and the dead kilometer of this line due to the first departure from garages is;

$$4x(Edirnekapı - Beylikduzu) + 1x(Edirnekapı - Zincirlikuyu) + 5x(Avcılar - Beylikduzu) + 9x(Beylikduzu - Beylikduzu + 4x(Hasanpasa - Zincirlikuyu) \quad (1)$$

It can be calculated as in Equation (1). However, this is not enough. There also occurs a dead kilometer due to return of these buses to the garage they are linked to. At this point, we shall use the RETURN column next to point A and B of each line in Table 2. This information tells us from which point the buses going to point A or B of any line will return to the garage without passengers at the end of the day.

When we look back to line 7, we see that 4 buses leaving the Edirnekapi garage and going to point A at the beginning of the day will go back to their garage from point B at the end of the day without any passengers, 1 bus going out from the Edirnekapi garage to point B at the beginning of the day will go back to its garage from point A at the end of the day, 5 buses going out from the Avcilar garage to point A at the beginning of the day will go back to their garage from point A at the end of the day, 9 buses going out from the Beylikduzu garage to point A at the beginning of the day will go back to their garage from point A at the end of the day and 4 buses going from the garage of Hasanpasa to the point B at the beginning of day will return to their garage from point B at the end of the day. This causes dead kilometer to the garage. The sum total of dead kilometer due to departures from and returns to the garage gives the total dead kilometer of the line.

Type	No	Line Code	EDIRNEKAPI				AVCILAR				BEYLIKDUZU				HASANPASA				Total
			A	RETURN	B	RETURN	A	RETURN	B	RETURN	A	RETURN	B	RETURN	A	RETURN	B	RETURN	
Splity duty	1	34(morning)	17	B	10	A	7	A		A		A		A		B		B	34
	2	34(evening)	13	B	14	A	7	A		A		A		A		B		B	34
	3	34A(morning)		A		A		A		A		A		A		B		B	0
	4	34A(evening)		A		A		A		A		A		A		B		B	0
	5	34AS(morning)	15	A		A	17	A		A		A		A		B	10	B	42
	6	34AS(evening)	7	B	8	A	17	A		A		A		A		B	10	B	42
	7	34BZ(morning)	4	B	1	A	5	A		A	9	A		A		B	4	B	23
	8	34BZ(evening)	3	B	2	A	5	A		A	9	A		A		B	4	B	23
	9	34C(morning)		B	28	B	1	A	8	A	20	A		A		B		B	57
	10	34C(evening)		B	28	B		A	9	A	20	A		A		B		B	57
	11	34G(morning)		B		B		A		A		A		A		B		B	0
	12	34G(evening)		B		B		A		A		A		A		B		B	0
	13	34Z(morning)	16	B		B		A		A		A		A		B	27	B	43
	14	34Z(evening)	16	B		B		A		A		A		A		B	27	B	43
Depot changed duty	15	34(morning)		B		B		A		A		A		A		B		B	0
	16	34(evening)		B		B		A		A		A		A		B		B	0
	17	34A(morning)		A		A		A		A		A		A		B		B	0
	18	34A(evening)		A		A		A		A		A		A		B		B	0
	19	34AS(morning)	15	B		B	1	A		A		A		A		B	12	B	28
	20	34AS(evening)	13	A	2	B	1	A		A		A		A		B	12	B	28
	21	34BZ(morning)	2	B	1	B	8	A		A	3	A		A		B		B	14
	22	34BZ(evening)	1	B	2	A		A	8	A	3	A		A		B		B	14
	23	34C(morning)		B		B		A		A		A		A		B		B	0
	24	34C(evening)		B		B		A		A		A		A		B		B	0
	25	34G(morning)		B		B		A		A		A		A		B		B	0
	26	34G(evening)		B		B		A		A		A		A		B		B	0
	27	34Z(morning)		B		B		A		A		A		A		B		B	0
	28	34Z(evening)		B		B		A		A		A		A		B		B	0
Normal	29	34	17	B		B		A		A		A		A		B	4	B	21
	30	34A		A		A		A		A		A		A		B		B	0
	31	34AS	28	A		A	17	A		A		A		A		B	37	B	82
	32	34BZ	46	B	4	B	27	A		A	9	A		A		B	30	B	116
	33	34C		B	6	B	5	A		A	2	A		A		B		B	13
	34	34G	3	B	4	A	4	A		A		A		A		B	4	B	15
	35	34Z		B		B		A		A		A		A		B	11	B	11

Table 2: Garage Based Departures of BRT Lines

In this case, the total dead kilometer of line B is:

$$4x[(Edirnekapı - Beylikduzu) + (Zincirlikuyu - Edirnekapı)] + 1x[(Edirnekapı - Zincirlikuyu) + (Beylikduzu - Edirnekapı]+5x[Avcılar-Beylikduzu+Beylikduzu-Avcılar]+9x[Beylikduzu-Beylikduzu+Beylikduzu-Beylikduzu]+4x[(Hasanpasa - Zincirlikuyu) + (Zincirlikuyu - Hasanpasa)] \quad (2)$$

It is as shown in Equation (2). Table 3 shows the distance from garages to point A and B and numeric value of the total dead kilometer for line 7 can be calculated by using this table.

Line Code	EDIRNEKAPI		AVCILAR		BEYLIKDUZU		HASANPASA	
	A	B	A	B	A	B	A	B
34	21	10,1	0	31,2	10	39,9	42,5	13,1
34A	2,4	21,4	19,9	42,5	28,6	51,2	24,1	0
34AS	22,3	21,4	0	42,5	10	51,2	42,5	0
34BZ	31	10,1	10	31,2	0	39,9	51,2	13,1
34C	31	0	10	19,9	0	31	51,2	24,1
34G	31	21,4	10	42,5	0	51,2	51,2	0
34Z	10,1	21,4	31,2	42,5	39,9	51,2	13,1	0

Table 3: The distance from garages to point A and B (km)

On the basis of this information, the current total dead kilometer of line 7 is as follows:

$$4x(31+10{,}1)+1x(10{,}1+31)+5x(10+10)+9x(0+0)+4x(13{,}1+13{,}1)=410{,}3\ km \quad (3)$$

On the basis of Equation (3) the dead kilometer is calculated as 410.3 kilometers. Here, the calculation of current dead kilometer for 7th line 34BZ is explained. This calculation is used for the whole system. Here we use the indexes:

- Line index, i∈I= {1,2…35), number of lines = 35
- Garage index, j∈J={1,2,3,4}, number of garages = 4
- First point index, k∈K= {1,2},1=A point, 2=B point

We need the parameters in addition to the indexes to calculate the dead kilometer of the whole system. These parameters are:

- x_{ijk}: the number of buses departing garage number j and going to first point k on line number i
- d_{ijk}: the dead kilometer covered by buses departing garage number j and going to first point k on line number i
- e_{ijk}: the dead kilometer covered by buses returning to garage number j from last point k on line number i
- n_{ik}: the number of buses that must be at point k on line number i
- g_j: maximum number of buses that can be parked in garage j

On the basis of the indexes and parameters above, the formulation stated in Equation (4) can be used to calculate the current dead kilometer of the whole system

$$\sum_{i=1}^{35}\sum_{j=1}^{4}\sum_{k=1}^{2} x_{ijk}.(d_{ijk}+e_{ijk}) \quad (4)$$

When the formula is applied to all lines, the current dead kilometer of the system is calculated as13.123,50 km per day.

3. Dead Kilometer Optimization

In this section of the study, we will design a model with linear programming method using the data available and make bus-garage distribution to minimize the dead kilometer. In the minimization model designed, the optimum bus distribution will be made according to the determined constraints so that the objective function will give the minimum value.

$$MIN\ Z_1=\sum_{i=1}^{35}\sum_{j=1}^{4}\sum_{k=1}^{2} x_{ijk}.(d_{ijk}+e_{ijk}) \quad (5)$$

$$\sum_{j=1}^{4} x_{ijk}=n_{ik}, \forall i\in I, \forall j\in J, \forall k\in K \quad (6)$$

$$\sum_{i=1}^{27}\sum_{k=1}^{2} x_{ijk}+\sum_{t=29}^{35}\sum_{k=1}^{2} x_{tjk}\le g_j \qquad i=2n+1, n=\{0,1\ldots 13\}\ ,\forall i\in I,\forall j\in J,\forall k\in K,\forall t\in T \quad (7)$$

$$\sum_{i=1}^{27}\sum_{k=1}^{2} x_{i+1jk}+\sum_{t=29}^{35}\sum_{k=1}^{2} x_{tjk}\le g_j \qquad i=2n+1, n=\{0,1\ldots 13\}\ ,\forall i\in I,\forall j\in J,\forall k\in K,\forall t\in T \quad (8)$$

$$restrictions\ on\ not\ sending\ buses\ from\ the\ extreme\ point\ garages\ to\ extreme\ point\ starting\ points \quad (9)$$

$$\sum_{k=1}^{2} x_{ijk}=\sum_{k=1}^{2} x_{i+1jk} \qquad \forall i\in I,\forall j\in J,\forall k\in K \qquad i=2n+1, n=\{0,1\ldots 13\} \quad (10)$$

$$x_{ijk}\ge 0, \forall i\in I,\forall j\in J,\forall k\in K \quad (11)$$

$$x_{ijk}\in Z^{+}, \forall i\in I,\forall j\in J,\forall k\in K \quad (12)$$

Equation (5) describes the objective function. In the current situation analysis, the current dead kilometer of the system is calculated with the formulation used in the same structure. As the objective is to minimize this kilometer, it is imported as minimization.

Equation (6) is the constraint describing the number of buses in each line to start from point A and B. For instance, at the beginning of line 7, there must be 18 buses at point A and 5 buses at point B. This expression means:

$$x_{711} + x_{721} + x_{731} + x_{741} = 18 \quad (13)$$
$$x_{712} + x_{722} + x_{732} + x_{742} = 5 \quad (14)$$

As described in Equation (13) and Equation (14), the number of buses departing from four garages and going to point A is 18 and the number of buses departing from four garages and going to point B is 5

Equation (7) and Equation (8) give the capacity constraints of the garages. The total number of busses departing a garage and going to point A or B cannot exceed the garage capacity. The capacities of the garages are shown in Table 4. The reason why the garage capacity constraints are shown twice is that ensure the interaction between the garage capacity constraints and the decision variable expressing the number of split duty and depot changed duty buses which are shown as separate lines in the morning and in the evening

Garage No	Garage Name	Number of Buses
1	Edirnekapi	224
2	Avcilar	101
3	Beylikduzu	40
4	Hasanpasa	140

Table 4: Garage Capacities

As Equation (9) cannot be generalized, it is expressed verbally. The beginning points of the lines were analyzed as extreme points were determined. The first extreme point group is Avcilar and Beylikduzu and the second extreme point is Sogutlucesme. The route of Istanbul BRT as shown in Figure 1 may give information on extreme points. It is not desired to send buses from Avcilar or Beylikduzu garages, which are the first extreme garage group, to the lines starting from Sogutlucesme, and from Hasanpasa garage, which is the second extreme garage, to the lines starting from Avcilar or Beylikduzu. This assumption is due to the fact that the first travel of the bus drivers is not desired to be without passengers. This assumption was made because the start times of 50-60 mins of bus drivers with 480 minutes of shift duration will be travelled without passengers if buses are sent from one extreme garage to extreme point and, therefore, the passengers waiting in the stations will suffer even if the optimal result is reached. To give an opinion, some of the constraints will be explained. Point A of 7th line 34 BZ is the Beylikduzu. It is, therefore, located at the first extreme point. According to the rule in Equation (9), it is not desired to get a bus to the point A of the 7th line from Hasanpasa garage which is the second extreme garage.

$$x_{741} = 0 \quad (15)$$

Similarly, point A of 34AS line is Avcilar and point B is Sogutlucesme. It is not desired to get a bus to the point A from Hasanpasa garage and to point B from Avcilar and Beylikduzu garages.

$$x_{541} = 0 \quad (16)$$
$$x_{522} = 0 \quad (17)$$
$$x_{532} = 0 \quad (18)$$

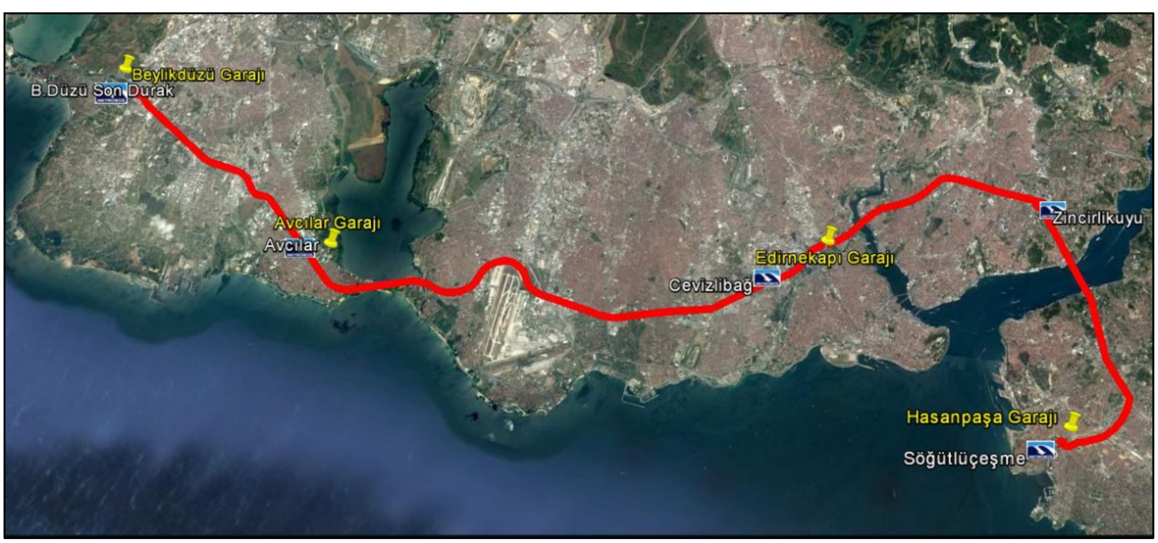

Figure 1: Istanbul BRT Route

The constraint on Equation (10) is constructed to ensure equality of the number of busses departing the garage in the morning and retuning back to garage in the evening for the splity duty and depot changed duty operation modes. Indeed, the busses leaving the garage in the morning and in the evening, are the same buses in these modes of operation. As stated before, there are 4 levels of dead kilometer in these modes of operation. If this equality constraint is not set, the model may suggest taking a bus from a garage in the morning to another garage in the evening, which is not desirable. The lines operation on splity duty and depot changed duty modes are those with the first 27 indexes among the lines shown in Table 2. For instance, the buses operating on splity duty mode on 34BZ line in the morning are shown as line 7 while those in the evening are shown as line 8. According to the condition described here, the number of buses on line 7 and line 8 must be equal.

$$x_{711} + x_{712} = x_{811} + x_{812} \quad (19)$$
$$x_{721} + x_{722} = x_{821} + x_{822} \quad (20)$$
$$x_{731} + x_{732} = x_{831} + x_{832} \quad (21)$$
$$x_{741} + x_{742} = x_{841} + x_{842} \quad (22)$$

As seen in Equation (19), Equation (20), Equation (21) and Equation (22), the buses of 34BZ line operating on splity duty mode with departure from 4 garages in the morning are set to depart from the same garage in the evening.

Equation (11) and Equation (12) are the constraints to ensure that each variable will be assigned as a whole number greater than 0

When the objective function and the above-mentioned constraints are run in LINDO 6.1 program, the total dead kilometer of the system is calculated as 8.640,30 km. The dead kilometer in the current situation was 13.123,50 km. Here we have a savings of 4.483,20 km per day. This savings is gained only by changing the garages linked to the lines in line with the result of the linear programming.

4. Results

The redistribution of lines according to the garages and the first starting points in the result of optimization is given in Table 5. At the output of the optimization, the current situation numbers in the lines are preserved, and only the dead kilometer have been minimized by changing the garages feeding these lines. This change provided a dead kilometer savings of 4.483,20 km per day. A bus operating on the BRT line consumes 0,561-liter fuel per kilometer. On the basis of this information;

$$4.483{,}20 \; x \; 0{,}561 = 2.515{,}08 \; lt \quad (23)$$

As seen in Equation (23), there is a fuel saving of 2.515,08 liters per day due to the decrease in dead kilometer in the result of optimization. General Directorate of IETT pays 4,01 TL/lt to the fuel with a discount of %13,5 on the normal selling price of 4,64 TL/lt. As the cost of 1 liter fuel is 4,01 TL;

$$2.515{,}08 \; x \; 4{,}01 = 10.085{,}43 \; TL \quad (24)$$

Type	No	Line Code	EDIRNEKAPI				AVCILAR				BEYLIKDUZU				HASANPASA				Total
			A	RETURN	B	RETURN	A	RETURN	B	RETURN	A	RETURN	B	RETURN	A	RETURN	B	RETURN	
Splity duty	1	34(morning)	4	B		A	20	A		A		A		A		B	10	B	34
	2	34(evening)		B	4	A	20	A		A		A		A		B	10	B	34
	3	34A(morning)		A		A		A		A		A		A		B		B	0
	4	34A(evening)		A		A		A		A		A		A		B		B	0
	5	34AS(morning)	8	A		A	24	A		A		A		A		B	10	B	42
	6	34AS(evening)		B	8	A	24	A		A		A		A		B	10	B	42
	7	34BZ(morning)	1	B		A		A		A	17	A		A		B	5	B	23
	8	34BZ(evening)		B	1	A		A		A	17	A		A		B	5	B	23
	9	34C(morning)	2	B	36	B		A		A	19	A		A		B		B	57
	10	34C(evening)	1	B	37	B		A		A	19	A		A		B		B	57
	11	34G(morning)		B		B		A		A		A		A		B		B	0
	12	34G(evening)		B		B		A		A		A		A		B		B	0
	13	34Z(morning)		B		B		A		A		A		A	16	B	27	B	43
	14	34Z(evening)		B		B		A		A		A		A	16	B	27	B	43
Depot changed duty	15	34(morning)		B		B		A		A		A		A		B		B	0
	16	34(evening)		B		B		A		A		A		A		B		B	0
	17	34A(morning)		A		A		A		A		A		A		B		B	0
	18	34A(evening)		A		A		A		A		A		A		B		B	0
	19	34AS(morning)	2	B		B	14	A		A		A		A		B	12	B	28
	20	34AS(evening)		A	2	B	14	A		A		A		A		B	12	B	28
	21	34BZ(morning)	9	B		B		A		A	4	A		A		B	1	B	14
	22	34BZ(evening)		B	9	A		A		A	4	A		A		B	1	B	14
	23	34C(morning)		B		B		A		A		A		A		B		B	0
	24	34C(evening)		B		B		A		A		A		A		B		B	0
	25	34G(morning)		B		B		A		A		A		A		B		B	0
	26	34G(evening)		B		B		A		A		A		A		B		B	0
	27	34Z(morning)		B		B		A		A		A		A		B		B	0
	28	34Z(evening)		B		B		A		A		A		A		B		B	0
Normal	29	34	17	B	4	B		A		A		A		A		B		B	21
	30	34A		A		A		A		A		A		A		B		B	0
	31	34AS	2	A		A	43	A		A		A		A		B	37	B	82
	32	34BZ	82	B	34	B		A		A		A		A		B		B	116
	33	34C	7	B	6	B		A		A		A		A		B		B	13
	34	34G	7	B		A		A		A		A		A		B	8	B	15
	35	34Z		B		B		A		A		A		A		B	11	B	11

Table 5: Optimization Outputs

According to the calculation in Equation (24) there is a saving of 10.089,96 TL per day on fuel costs. The greenhouse gas emission due to mobile consumption of IEET is 1,43 kg per kilometer (IETT, 2016). On the basis of this information;

$$4.4483{,}20\ x\ 1{,}43 = 6.410{,}98\ kg \qquad (25)$$

As one can see in Equation (25), it will also contribute to the environment by decreasing the CO_2 emission will by 6.410,98 kg per day.

Unit	Current	Optimization	Saving
Dead kilometer (km)	13.123,50	8.640,30	4.483,20
Fuel Amount (lt)	7.362,28	4.847,21	2.515,08
Fuel Unit Price (TL/lt)	4,01		
Fuel Cost (TL)	29.522,74	19.437,31	10.085,43
CO_2 emission per kilometer (kg/km)	1,43		
Total amount of CO_2 emission (kg)	18.766,61	12.355,63	6.410,98

Table 6: Comparison of Current Status and Optimization in a Work Day

If we are to summarize the results, if the study is implemented;

- The daily dead kilometer will decrease from 13.123,50 km to 8.640,30 km with a saving of 4.483,20 km,
- The fuel amount will decrease from 7.362,28 lt to, 4.847,21 lt with a saving of 2.515,08 lt,
- The cost of fuels will decrease from 29.522,74 TL to 19.437,31 TL with a saving of 10.085,43 TL
- Total amount of CO_2 emission to environment will decrease from 18.766,61 kg to 12.355,63 kg with a saving of 6.410,98 kg.

6. References

i. Agrawal, A.K., Dhingra, S.L., 1989, “An Optimal Program for Augmentation of Capacities of Depots and Shipment of Buses from Depots to Starting Points of Routes,” Indian Journal of Pure and Applied Mathematics, Vol. 20, No. 2, s. 111-120.

ii. Djiba, C.B., Balde, M., Ndiaye, B.M., Faye, R.M., Seck, D., 2012, “Optimizing Dead kilometer in Urban Bus Routes. Dakar Dem Dikk Case Study”, Journal of Transportation Technologies, 2012, 2, s. 241-247.

iii. IETT İşletmeleri Genel Müdürlüğü 2014-2015 Sürdürülebilirlik Raporu, 2016, s.78

iv. Kepaptsoglou, K., Karlaftis, M., Bitsikas, T., 2009, “Bus-To-Depot Allocation: Models and Decision Support System”, Journal of Transportation Engineering, Volume 136, Issue 7, s. 600-605.

v. Mahadikar, J., Mulangi, R.H., Sitharam, T.G., 2015, “Optimization Of Bus Allocation To Depots By Minimizing Dead Kilometers”, Journal of Advanced Transportation 2015:49, s. 901-912.

vi. Nasiboğlu, E., Eliyi, U., Özkılıç, M., Kuvvetli, Ü., 2011, “Şehiriçi Toplu Taşımada Ölü Kilometre Minimizasyonu İçin Bir Uygulama”, Endüstri Mühendisliği Yazılımları ve Uygulamaları Kongresi | 30 Eylül-01/02 Ekim 2011, s.135-146.

vii. Pepin, A.S., Desaulniers, G., Hertz, A., Huisman, D., 2006, “Comparison Of Heuristic Approaches For The Multiple Depot Vehicle Scheduling Problem”, Journal of Scheduling Vol.12 Issue 1.

viii. Prakash, S., Balaji, B.V., Tuteja, D., 1999, “Optimizing Dead kilometer In Urban Bus Routes Through A Nondominated Solution Approach”, European Journal of Operational Research 114, s.465-473.

ix. Prakash, S., Saini, V., 1989, “Selection Of Optimal Site For New Depot Of Specified Capacity With Two Objectives”, Indian J.Pure Appl. Math, 20(5), s.425-432.

x. Sharma, V., Prakash, S., 1986, “Optimizing Dead kilometer In Urban Bus Routes”, Journal of Transportation Engineering, Vol.112 No.1, s.121-129.

xi. Sridharan, R., 1991, “Allocation of Buses to Depots: A Case Study”, Vikalpa 16 No. 2, s.27-32.

xii. Uyeno, D.H., Willoughby, K.A., 1995, “Transit Center Location-Allocation Decisions”, Transpn. Res.-A. Vol.29A No.4, s.263-272.

xiii. Van Der Perre, P., Van Oudheusden, D., 1996, “Reducing Depot-Related Costs of Large Bus Operators A Case Study In Bangkok”, European Journal of Operational Research (96), s.45-53.

xiv. Waters, N.M., Wirasinghe, S.C., Babalola, A., Marion, K.E.D., 1986, “Location of Bus Garages”, Journal of Advanced Transportation Volume 20, Issue 2, s. 133-150.

xv. Willoughby, K.A., 2001, “A Mathmatical Programming Analysis Of Public Transit Systems”, Omega Vol.30 Issue 3, s. 137-142.

xvi. Willoughby, K.A., Uyeno, D.H., 2001, “Resolving Splits In Location/Allocation Modeling: A Heuristic Procedure For Transit Center Decisions”, Transportation Research Part E 37, s.71-83.