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A MATHEMATICAL MODEL FOR THE LOCATION OF CHARGING STATION FOR ELECTRIC BUSES

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Keywords

Electric bus
Charging station
Mix integer linear programming,
Multi objective optimization
Weighted sum method

Abstract

In order to create sustainable solutions, the use of electric vehicles instead of traditional vehicles, which is called fossil fuel vehicles, is significant. It is essential to determine the locations of the charging stations to be established so that electric vehicles can be preferred in intercity buses, which are frequently used in the transportation network. For the selection of locations of the charging stations, there are limitations such as waiting times at the charging stations, having sufficient charge for the next stop, and especially the budget. In addition, determining the candidate charging stations among the existing bus stops would increase customer satisfaction as it would prevent extra breaks. However, it may not be possible to use electric buses on every bus route due to both driving range and budget constraints. For this reason, in this paper, a multi-objective mathematical model that minimizes the number of charging stations and maximizes the number of electric buses is proposed

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and the weighted sum method is used to solve this model. In addition, the proposed mathematical model was solved using the General Algebraic Modeling System (GAMS) with the data of a bus company in Türkiye.

ŞEHİRLERARASI ELEKTRİKLİ OTOBÜSLER İÇİN ŞARJ İSTASYONU KONUMUNUN BELİRLENMESİNE YÖNELİK MATEMATİKSEL MODEL

Anahtar Kelimeler

Elektrikli otobüs
Şarj istasyonu
Karma tamsayılı doğrusal programlama
Çok amaçlı optimizasyon
Ağırlıklı toplam yöntemi

Öz

Sürdürülebilir çözümler oluşturmak için fosil yakıtlı araçlar olarak adlandırılan geleneksel araçlar yerine elektrikli araçların kullanımı önem arz etmektedir. Ulaşım ağında sıklıkla kullanılan şehirlerarası otobüslerde elektrikli araçların tercih edilebilmesi için kurulacak şarj istasyonlarının yerlerinin belirlenmesi esastır. Şarj istasyonlarının yer seçiminde, şarj istasyonlarında bekleme süreleri, bir sonraki durak için yeterli şarjın olması ve özellikle bütçe gibi sınırlamalar bulunmaktadır. Ayrıca mevcut otobüs durakları arasından aday şarj istasyonlarının belirlenmesi ekstra molaların önüne geçeceğinden müşteri memnuniyetini artıracaktır. Ancak hem sürüş mesafesi hem de bütçe kısıtlamaları nedeniyle her otobüs güzergahında elektrikli otobüs kullanmak mümkün olmayabilir. Bu nedenle, bu çalışmada şarj istasyonu sayısını minimize eden ve elektrikli otobüs sayısını maksimize eden çok amaçlı bir matematiksel model önerilmiş ve bu modeli çözmek için ağırlıklı toplam yöntemi kullanılmıştır. Ayrıca önerilen matematiksel model, Türkiye'deki bir otobüs firmasının verileri ile Genel Cebirsel Modelleme Sistemi (GAMS).

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1. Introduction

Creating more sustainable ways are getting significant for the future of the world. Thus, the importance of switching to the electric vehicles is increasing day by day in order to reduce the damage of vehicles working with fossil fuels, which we refer to as traditional vehicles. The electric vehicles with full battery travel less range than conventional vehicles with full of gas and has a certain battery charge time. This situation has led to studies to determine the locations of charging stations.

Hosseini and MirHassani (2015) studied a two-stage model of stochastic reloading stations in which the first stage is located at permanent stations and the second stage with portable stations. Liu, Niu, Xu and Li (2016) conducted a study on the capacities of battery exchange stations by considering the batteries of electric vehicles. Determining the location of charging stations is divided into fixed stations and portable stations. Gagarin and Corcoran (2018) modeled the problem as a multiple dominance problem on reachability graphs covering real road networks in Boston and Dublin. Xie, Liu, Li, Lin and Huang (2018) worked on a multi-stage and chance-limited stochastic model for strategic planning of battery electric vehicle intercity fast charging infrastructure. Sun, Gao, Li and Wang (2020) presented a mixed integer programming model that aims to maximize the electric vehicle density by considering the intercity travels of individuals. Guo, Yu, Li, Yang, Yao and Lin (2020) studied the problem of locating charging stations for electric taxis. The problem involves the integration of two interrelated decision subproblems; location optimization of charging centers, optimization of battery exchange stations. They presented a minimum cost model for the solution and included a corresponding algorithm. Dinc Yalcin, Ozsoy and Taskin (2021) dealt the location of the charging stations placement problem with multi-objectives: minimizing the number of charging stations and minimizing the distance among charging stations and between the regions in urban areas and charging stations. They also considered the network constraints. All of these studies are for the individual usage electric vehicles.

It is possible to talk about the increase in the use of buses, based on the fact that the studies are based on public transportation vehicles rather than individual electric vehicle use. When most of the studies are examined, it is seen that instead of determining the location of charging stations for private vehicles, infrastructure studies of public transportation vehicles are also emphasized. Sasaki, Araki, Miyata and Kawaji (2002) mentioned that they have developed a hybrid vehicle for low-floor city buses with an improved capacitor system and miller cycle CNG engine, and the positive results of voltage distribution and fuel use for a 14-tonne bus. Wu and Bucknall (2013) discussed the conceptual design of a hybrid engine to replace the conventional diesel internal combustion engine for Route 226 in London. As a result of the performance evaluation, it is concluded that the cost of the hybrid vehicle is cheaper and more powerful. The motor and batteries suggested as a result of the study are a guide for the next studies. As a result of the study (Rogge, Wollny and Sauer, 2015) of the bus network in Muenste, a medium-sized city in Germany, with real data, they underlines the need to focus on whole vehicle programs rather than individual journeys. Uslu and Kaya (2021) recently studied a mathematical model for the location of charging stations of intercity buses considering waiting times of intercity buses at charging stations and the routes, the demand on the routes and driving ranges are taken into account in the mathematical model.

Additional, all intercity buses in a country are considered as electrical bus and then the model is applied on the case of Turkey.

In this paper, we handle the location of charging stations for intercity buses and we propose a mathematical model. Then, we solve the mathematical model with the data of an intercity bus company in Türkiye and obtain solutions. Our contribution can be summarized as follows:

- We consider the budget as a constraint since all intercity buses may not be electric buses due to the budget. Thus our model contains an another decision variable with the difference of literature: the number and the which of electric buses besides the number and location of charging stations.
- As a matter of making the number of electric buses as decision variable, the frequency of the electric buses for each electric station becomes a decision variable in contradistinction to literature.
- The current stopping place of buses are considered as the candidate of the charging stations since the route of the intercity buses can remain the same.
- We limit the maximum time allowed for each charging station and addition we define a decision variable that indicate the time needed for each electric bus at each charging station on the route of related electric bus. Inherently the time should be less than the maximum time.
- Hereby, we construct a multi-objective mathematical model: maximizing the number of electric bus, minimizing the number of charging stations. Further, the multi objective model is solved by weighted sum method.
- We apply our model for a intercity bus company serving in Türkiye.

The rest of the paper is organized as follows. In Section 2, we explain the proposed mathematical model in details. In Section 3, we give the data of the case study and present the solutions. Finally in Section 4, we draw conclusion.

2. Mathematical Model

In this section, we explain the sets, parameters and decision variables used in the mathematical model.

Sets:

I: The set of intercity bus stops

K: The set of intercity buses

C: The set of capacity of charging stations

Parameters

f: Percentage of charging electric buses battery per minute

dr: Driving range that the electric bus can travel with a full charge

p: Percentage of battery reduction of the electric bus per kilometers ($\frac{1}{dr}$)

T: The maximum allowable time to stay in a charging station

d_{ij}: The distance between ith stop and jth stop $i,j \in I$

r_{ijk}: $\begin{cases} 1, \text{If the } k\text{th bus is going from the } i\text{th stop to the } j\text{th stop} \\ 0, \text{otherwise} \end{cases}$ $i,j \in I, k \in K$

sn_k: The number of services (trips) of kth bus in a day $k \in K$

cs_c: The cost of constructing c stations in a stop $c \in C$

cb: The cost of a electric bus

V_c: The service rate of a station with c capacity ($V_c = c * 12 * 60$) $c \in C$

B: Budget

Decision Variables

x_{ic}: $\begin{cases} 1, \text{if a station with a capacity of } c \text{ is established at the } i\text{th stop} \\ 0, \text{otherwise} \end{cases}$

e_k: $\begin{cases} 1, \text{If the } k\text{th intercity bus becomes electric bus} \\ 0, \text{otherwise} \end{cases}$

b_{ik}: Percentage of the state of charge (SoC) of battery of the kth intercity electric bus while leaving the ith stop

t_{ik}: Charging time of the kth intercity electric bus at the ith charging station

μ_i: The service rate of ith charging station

λ_i: The arrival rate of the intercity electric buses to the ith charging station

Mathematical Model

$$z_1 = \min \sum_{i \in I} \sum_{c \in C} x_{ic} \tag{1a}$$

$$z_2 = \max \sum_{k \in K} e_k \tag{1b}$$

$$\sum_{c \in C} x_{ic} \leq 1 \ \forall i \in I \tag{2}$$

$$\sum_{i \in I} \sum_{c \in C} cs_c \,.\, x_{ic} + \sum_{k \in K} cb.\, sn_k .\, e_k \leq B \tag{3}$$

$$\left(\sum_{j \in I} r_{ijk} \,.\, p.\, d_{ij} \right).\, e_k \leq \ b_{ik}, \qquad \forall\ i \in I, k \in K \tag{4}$$

$$b_{ik} \leq \ e_k, \qquad \forall\ i \in I, k \in K \tag{5}$$

$$t_{ik} \leq T.\sum_{c \in C} x_{ic} \ \ \forall i \in I, k \in K \tag{6}$$

$$t_{ik} \leq T.\, e_k \sum_{j \in I, j \neq i} r_{ijk} \ \ \forall i \in I, k \in K \tag{7}$$

$$b_{ik} = \ t_{ik}.\, f.\left(\sum_{j \in I, j \neq i} r_{ijk} \right) + \sum_{j \in I, j \neq i} \left(b_{jk}.\, r_{jik} - \ e_k.\, r_{jik}.\, p.\, d_{ji} \right), \ \forall\ i \in I, k \in K \tag{8}$$

$$\mu_i = \sum_{c \in C} x_{ic} \,.\, V_c, \qquad \forall i \in I \tag{9}$$

$$\lambda_i = \sum_{k \in K} sn_k .\, t_{ik}, \qquad \forall i \in I \tag{10}$$

$$\mu_i - \ \lambda_i \geq \ \frac{1}{T}.\sum_{c \in C} x_{ic}, \qquad \forall i \in I \tag{11}$$

$$\left(\sum_{j \in I, j \neq i} r_{ijk} - \sum_{j \in I, j \neq i} r_{jik} \right).\, e_k \leq b_{ik} \ \forall i \in I, k \in K \tag{12}$$

$$\left(\sum_{j \in I, j \neq i} r_{jik} - \sum_{j \in I, j \neq i} r_{ijk} \right).\, e_k \leq \sum_{c \in C} x_{ic} \ \ i \in I, k \in K \tag{13}$$

$$x_{ic} \in \{0,1\} \forall i \in I, c \in C \tag{14}$$

$$e_k \in \{0,1\} \forall k \in K \tag{15}$$

$$b_{ik}, t_{ik} \geq 0 \ \forall i \in I, k \in K \tag{16}$$

$$\mu_i, \lambda_i \geq 0 \ \forall i \in I \tag{17}$$

The problem has two objectives: minimizing the numbers of stations (1a) and maximizing the number of electric bus (1b). Equation (2) implies that at most one charging station having capacity c must be assigned for each station. Equation (3) implies that sum of the total cost of stations and the total cost of intercity electric buses should not be over the budget. Equation (4) implies the SoC of the battery of the intercity electric bus when leaving a node should be equal or over than the needed battery level to travel from one node to another node. Equation (5) implies that, if the kth bus is an intercity electric bus, SoC of the battery should be computed and can be 1 at most. Equations (6) and (7) imply that the charging time should not be over waiting time at the stop if the stop has a charging station, the intercity bus is chosen as electric intercity bus, and the stop of the relevant charging station is on the route of the relevant intercity electric bus, respectively. In equation (8), the first sum implies that the SoC of the battery based on charging time and the second sum shows the remaining SoC of the battery from the previous travelling. So, the SoC of the battery of the intercity electric bus when leaving a node should be equal the sum of these two terms. Equation (9) shows that the service rate equals to the rate of a station with c capacity times the service rate which is calculated as $V_c = c * 12 * 60\ \forall c \in C$. Equation (10) implies that the arrival rate of the intercity electric buses is directly based on frequency, charging time. Equation (11) implies that charging station service rate should satisfy the arrival rate of intercity electric buses (for this equation see also Uslu and Kaya, 2021). Equation (12) ensures that SoC of the battery of each intercity electric bus before leaving the starting stop is full. If a node is the starting stop for a intercity bus, the difference $\sum_{j\in I, j\neq i} r_{ijk} - \sum_{j\in I, j\neq i} r_{jik}$ is 1 since the intercity bus travels from the starting stop to an another node ($\sum_{j\in I, j\neq i} r_{ijk} = 1$) but does not travel from a node to the starting stop ($\sum_{j\in I, j\neq i} r_{jik} = 0$). For other nodes except the final stop and the final stop, the difference is 0 and -1, respectively. So the equation does not force the SoC to be 1 for other nodes except the starting stop. Equation (13) implies that the final stop should have a charging station. Equations (14)-(17) specify the variable domains.

2.1. Multi-Objective Optimization (MOP)

In multi-objective optimization (MOP), there are more than one objective function as $\min_{\mathbb{X}}[z_1, z_2, \dots, z_n]$ where $\mathbb{X}$ is the set of the problem constraints and $z_i: \mathbb{X} \to \mathbb{R}, i = 1, .., n$ are the objective functions of the problem. Thus, one optimal solution that optimize all objective functions cannot be obtained for most cases and a MOP has a Pareto optimal points that is the solution set of the MOP (see e.g. Marler and Arora, 2004).

A point $x * \in \mathbb{X}$ is defined as a Pareto optimal point if and only if the conditions (i) $z_i(x^*) \leq z_i(x)\ \forall i = 1, \dots, n$ and (ii) $z_i(x^*) < z_i(x)$ for at least one function i are satisfied for all $x \in \mathbb{X}$.

Various scalarization methods have proposed in literature and the aim of these methods are to formulate the multi-objective model within a single function (see Kasimbeyli, Kamisli Ozturk, Kasimbeyli, Dinc Yalcin and İcmen Erdem, 2019 for comparison of the methods). The weighted sum scalarization (WSS) proposed by Gass and Saaty (1955) is one of the most common scalarization technique used in the literature. The WSS merges the objectives functions with multiplying the functions by a weighted vector and then summing of the objective functions: $z_w = \min_{\mathbb{X}} \sum_i^n w_i z_i$. When the objective functions have different units, then a transformation is needed as normalization. One approach is divided the objective function by the absolute value of an upper limit z_i^u as $z_i^{trans} = \frac{z_i}{|z_i^u|}$, i=1,…,n (Proos, Steven, Querin and Xie, 2001; Marler and Arora, 2004). Note that $z_i^u \neq 0, i = 1, \dots, n$. Thus, the objective function of the WSS becomes $z_w = \min_{\mathbb{X}} \sum_i^n w_i z_i^{trans}$.

Since the second objective function (1b) is maximization, it should be turned to minimization as $z_2 = \max \sum_{k \in K} e_k = \min \sum_{k \in K} -e_k$. Then, the two objective functions are formulated by the WSS and normalization as in (18) where z_1^u and z_2^u may be taken as the maximum available number of charging stations and intercity electric bus, respectively. Since these values are positive, we omit the absolute value.

$$z_w = \min_{\mathbb{X}} \left[w_1 \frac{z_1}{z_1^u} + w_2 \frac{-z_2}{z_2^u} \right] = \min_{\mathbb{X}} \left[w_1 \frac{(\sum_i \sum_c x_{ic})}{z_1^u} + w_2 \frac{(-\sum_k e_k)}{z_2^u} \right] \tag{18}$$

3. Case Study: An Intercity Bus Company in Türkiye

This study complied with research and publication ethics.

We apply the model for a intercity bus company in Türkiye. After we explain the data that are needed for the parameters of the problem, we give the results for different values of driving range and budget. Also, we present a results in details with showing the values of the decision variables.

3.1. Problem Parameters of the Case Study

In this section, we explain the data of the company obtained for the parameters of the problem. Since an intercity electric bus may be charged full in 60 minutes (HT Auto, 2020), the percentage of charging electric buses battery per minute f is calculated as 0.016. The driving range with a full battery dr has a variety depending on the electric bus. For this reason, we take the driving range from the set $\{200, 300, 400, 500, 600\}$ in km (see e.g. HT Auto, 2020; Karsan, 2021), and the percentage of battery reduction of the electric bus per kilometers p is computed as $1/dr$. Thus the maximum time allowed for charging is defined as 60 minutes.

The stop points of the intercity buses are determined and the distance between all stops d_{ij} was obtained by General Directorate of Highways (2021) and Google Maps in km. There are 14 buses and 26 stops in all routes which are the number of the set K and the number of the set I, respectively. Then, it is checked whether each intercity bus pass through the stops as binary and recorded as the parameter $r_{ijk}, \forall i, j \in I, k \in K$. Moreover, the number of services (trips) of each intercity bus in a day $sn_k, \forall k \in K$ are as {2, 3,2,3,5,4,2,3,1,2,3,2,4,5}.

The cost of constructing $c, \forall c \in C$, $C = \{1, \dots, 10\}$ stations in a stop $cs_c, \forall c \in C$ are defines as (see Table 2 in Uslu and Kaya, 2021)

{\$205984, \$245082, \$257291, \$296388, \$ 335485, \$293924, \$ 319578, \$345232,

\$370886, \$396540}

and the cost of a electric bus cb is estimated as average \$115000 (see e.g. Ali Baba, 2021). The service rate of a station with c capacity V_c, $\forall c \in C$ in minutes is calculated as

{720, 1440, 2160, 2880, 3600, 4320, 5040, 5760,6480, 7200}

by using the formula $V_c = c * 12 * 60 \ \forall c \in C$ that we assumed that the charging stations serve 12 hours a day since the schedule of the intercity buses covers 12 hours of a day. Certainly, the intercity electric buses may be charged during night time, however our purpose is to define the service capacity of the charging stations during the intercity electric buses are in use since the recharging is needed when the intercity electric buses travel from one stop to another. Additional, the budget is form the set $\{1M, 2M, 3M, 4M, 5M, 6M, 7M\}$ in \$ where M presents million. Moreover, the weight are defined as $w_1, w_2 = (1,1)$ that means the objective functions are equally important. Finally, we used General Algebraic Modeling System (GAMS) CPLEX solver to solve the model. All parameters are shown in Table 1, briefly.

Table 1

Parameters and Sets of the Case Study in Summary

Sets or Parameter	Value
I:	$\{1, \ldots, 26\}$
K:	$\{1, \ldots, 14\}$
C:	$\{1, \ldots, 10\}$
f:	0.016
dr:	$\{200, 300, 400, 500, 600\}$
p:	$\{0.005, 0.003, 0.0025, 0.002, 0.0016\}$
T:	60 min.
sn_k:	$\{2, 3,2,3,5,4,2,3,1,2,3,2,4,5\}\ \forall k \in K$
cs_c:	$\{\$205984, \$245082, \$257291, \$296388, \$\ 335485, \$293924, \$\ 319578,$ $\$345232, \$370886, \$396540\}\ \forall c \in C$
cb:	\$115000
V_c:	$\{720,\ 1440, 2160,\ 2880, 3600, 4320, 5040, 5760, 6480, 7200\}\ \forall c \in C$
B:	$\{1M, 2M, 3M, 4M, 5M, 6M, 7M\}$

3.2 Results of the Case Study

We solve the mathematical model for the case study using the parameters that are explained in section 4.1 and given in Table 1. Objective functions values for different values of driving range and budget are given in Table 2 and demonstrated in Figure 1. Moreover total cost needed is given in Table 2. $1M budget with driving range 200 km is not enough to construct a charging station and certainly to buy an intercity electric bus. For driving range 200km, $2M budget is enough and increasing the budget does not change the solution. For driving ranges from 300km to 600 km, when the budget is increased until a specific value ($3M for 300 km, $6M for 400km, 500km, 600km), the number of charging stations and the number of intercity electric buses are increased. Until the specific value of budget does not change the solution in that the driving ranges limit the selection of routes of intercity bus as electric such that an intercity electric bus should travel from one stop to another stop within its route with full charge.

Table 2

Objective Functions Values with Different Values of Driving Range and Budget

Driving Range	Budget	z_1	z_2	z_w	Total Cost	Driving Range	Budget	z_1	z_2	z_w	Total Cost
200 km	$1M	0	0	0		500 km	$1M	3	2	1	$962,952
	$2M	4	3	1			$2M	4	4	0	$1,858,936
	$3M	4	3	1			$3M	6	6	0	$2,845,904
	$4M	4	3	1	$1,743,936		$4M	8	8	0	$3,832,872
	$5M	4	3	1			$5M	9	9	0	$4,498,856
	$6M	4	3	1			$6M	10	10	0	$5,049,840
	$7M	4	3	1			$7M	10	10	0	
300 km	$1M	3	2	1	$962,952	600 km	$1M	3	2	1	$962,952
	$2M	4	4	0	$1,858,936		$2M	4	4	0	$1,858,936
	$3M	6	6	0			$3M	6	6	0	$2,845,904
	$4M	6	6	0			$4M	8	8	0	$3,832,872
	$5M	6	6	0	$2,845,904		$5M	9	9	0	$4,498,856
	$6M	6	6	0			$6M	11	11	0	$5,830,824
	$7M	6	6	0			$7M	11	11	0	$5,830,824
400 km	$1M	3	2	1	$962,952						
	$2M	4	4	0	$1,858,936						
	$3M	6	6	0	$2,960,904						
	$4M	7	7	0	$3,626,888						
	$5M	8	8	0	$4,062,872						
	$6M	11	10	1	$5,244,824						
	$7M	11	10	1							

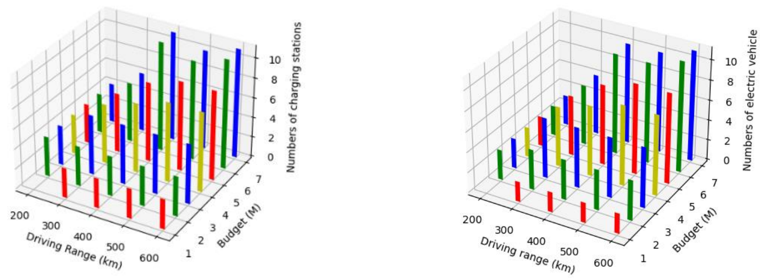

Figure 1. Number of Charging Stations (Left) and Number of Intercity Electric Buses (Right) with Different Values of Driving Range and Budget

3.3 Results of a Solution in Details

In this section, we explain decision variables for solutions that has the largest value of the number of charging stations and intercity electric buses- $(z_1, z_2) = (11,11)$ with 600km driving range and \$7M budget, and the values of the decision variables are given in Table 3 and 4.

Since the number of services (trips) of buses of the company is significant small, the charging stations which have one capacity $(c = 1)$ is enough. The arrival rate of the intercity electric buses λ_i to the relevant charging stations which are for the last stops are 0 in that the arrival rate is not deal for the last stop in the mathematical model since customers arrive their destination and each intercity bus has time for charging e.g. overnight.

Among 11 routes of electric intercity buses, 5 of them where $k = 7, 10, 11, 12, 14$ need to recharge for a while at the charging stations which are at way stop. The full battery is enough to travel all routes for 6 of them where $k = 2, 3, 6, 8, 9, 13$.

Table 3

The Selected Charging Station No, Their Capacity, the Service Rate of the Relevant Charging Station, the Arrival Rate Of the Intercity Electric Buses To the Relevant Charging Station

Charging station no, i where $x_{ic} = 1$	The capacity of charging station, c where $x_{ic} = 1$	μ_i	λ_i
1	8	720	600
7	1	720	71.88
8	6	720	688.15
9	1	720	0
10	1	720	0
15	1	720	0
16	6	720	587.960
18	1	720	0
19	1	720	0
20	3	720	300
21	1	720	0

Table 4

The Selected Intercity Electric Buses k where $e_k = 1$, Their Stops in Order, SoC of Battery Of the kth Intercity Electric Bus While Leaving the ith Stop- b_{ik}, And Charging Time of the kth Intercity Electric Bus at the ith Charging Station - t_{ik}

k	Stops of the intercity electric bus ($r_{ijk} = 1$ and $e_k = 1$)	b_{ik}	t_{ik}
2	8→3→2→1→14→17→18	1→0.961→0.934→0.882→0.829→0.795→0.766	60→0→0→0→0→0→0
3	20→18→17→14→1→2→3→9	1→0.930→0.901→0.867→0.813→0.762→0.735→0.14	60→0→0→0→0→0→0→0
6	1→2→3→8	1→0.948→0.922→0.882	60→0→0→0
7	1→2→4→5→6→7→21	1→0.948→0.917→0.816→0.757→1→0.615	60→0→0→0→0→20→0
8	1→2→3→8→11→12→13→9	1→0.948→0.922→0.882→0.734→0.427→0.341→0.292	60→0→0→0→0→0→0→0
9	1→2→3→8→26→6→7	1→0.948→0.922→0.882→0.788→0.687→0.604	60→0→0→0→0→0→0
10	8→7→21	1→1→0.61	60→17→0
11	8→3→2→1→14→17→18→20→19	1→0.961→0.934→0.882→0.829→0.795→0.766→1→0.950	60→0→0→0→0→0→0→60→0
12	8→3→2→1→17→14→16→15	1→0.961→0.934→0.882→0.786→0.751→1→0.918	60→0→0→0→0→0→24→0
13	16→17→14→1→2→3→8→9	1→0.911→0.877→0.824→0.772→0.745→0.706→0.143	60→0→0→0→0→0→0→0
14	16→17→14→1→2→3→8→10	1→0.911→0.877→0.824→0.772→0.745→1→0.090	60→0→0→0→0→0→18→0

4. Conclusion

In this study, we answered the two questions: "where the charging stations should be established" and "which intercity buses on the routes should be electric buses" under constraints of driving range, budget, having enough battery level to reach the next stop, the time needed for charging, having enough service rate for the arrival rate of the intercity electric buses. Two objective functions are defined to answer the questions: minimizing the number of charging stations and maximizing the number of the intercity electric buses. Additional, the budget which is also significant for a commercial company is used as a constrained to determine the number of charging stations and the number of electric vehicle. Moreover, the constraint about charging station service rate and the arrival rate of intercity electric buses are handled and the percentage of SoC of battery and time for charging at each stop are considered as constraints. Finally the model is solved by using weighted sum method which is the most common multi objective method.

Currently, there is no intercity electric bus fleet in Turkey yet. We applied the model for a company that serves intercity buses in Turkey and obtained solutions for different driving range and budget. It should be emphasized that the model is easily applied an another company with only changing the data. The company that is applied the mathematical model in this paper is relatively a small company.

As a future study, the model can be applied for bus companies which cover more cities. Moreover, if a solution within a reasonable time cannot be obtained for a case having large stops, then a heuristic or metaheuristic can be developed.

Contribution of Researchers

In this research, Gülçin DİNÇ YALÇIN contributed in writing, reviewing, and editing the paper, searching the literature, developing mathematical model as linear, coding model by optimization program, converting data into optimization model parameter, obtaining the results; Ece DOĞAN contributed in writing the paper, searching literature, obtaining data, developing mathematical model, coding model by optimization program, obtaining the results; Ahmed Yasin KAYA contributed in writing the paper, searching literature, obtaining data, developing mathematical model, coding model by optimization program, obtaining the results, and Enes Can OĞUZ contributed in writing the paper, searching literature, obtaining data, developing mathematical model, coding model by optimization program, obtaining the results.

Conflict of Interest

No conflict of interest has been declared by the authors.

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