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Research Article

TRIP OPTIMIZATION FOR PUBLIC TRANSPORTATION SYSTEMS WITH LINEAR GOAL PROGRAMMING (LGP) METHOD

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ABSTRACT

Determination of the optimum trip schedules is an important problem for public transportation systems. It is complex task to assign optimum number of vehicles and determine the trip schedules for a public transport systems which consist of many routes. In the case of taking infrequent trip schedules, the existing passenger demand is not satisfied. Therefore waiting times are increased in the bus stops. In contrary, with more frequent intervals, unutilized capacity and higher operational costs are expected. Also, intense traffic density and environmental pollution are associated with the frequent trips. The optimum trip frequencies of the passenger demands varies during the hours of a day and is important for passenger satisfaction and operation efficiency of the system. Trip scheduling and vehicle assignment studies take attention in the current literature assisted with different optimization techniques and artificial intelligence method. In this study, only 10 different bus routes which is operated privately, were considered in the city center of Antalya and the Linear Goal Programming (LGP) was used to determine the optimum number of vehicles operated on the routes. The study results showed that the existing system performance can be preserved by reducing the frequency of specific trips and LGP is stated as an efficient algorithm for determining the optimum trip frequencies and number of vehicles in a public transportation systems.
Keywords: Linear goal programming, public transportation, trip planning, passenger demand.

1. INTRODUCTION

Goal programming (GP) is a multi-objective optimization methodology, which is a branch of multi-criteria decision technique covering a wide range of recent literature [1-3]. The solution methodology for the GP algorithm was first proposed by Charnes and Cooper [2] and further improved by Lee [3] and Ignizio [4]. Until the mid of the 70's, the literature covering the GP was not broad. After the 70's numerous studies were carried out by many researchers such as Romero [5], Schniederjans [6] and Tamiz and Jones [7] who emphasized the effective use of the GP for many optimization problems. Today, the GP was applied for many fields and it is considered as a beneficial tool especially when it requires multi-purpose decision making [8]. Especially,

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Scnieederjans and Tamiz's studies revealed that LGP method has many effective application areas [9].

Some of the areas where the target programming technique is commonly used can be counted as production planning, nutritional problems, supplier selection, transportation and logistics problems, energy planning, labor planning, project selection and management, resource planning in hospitals, portfolio selection, financial planning, investment planning and various management applications.

A type of goal programming, Linear Goal Programming (LGP), is used when the functions forming the Hierarchy Process (HP) model are linear and also linear programming conditions are met [10]. The target in the GP model is an objective defined by a desired level. The objective can be defined as a reflection of a general expression under the control of decision makers [11]. In the LGP model, for each objective, a typical desired target value is determined and a goodness function is formulated [12]. This result is achieved by looking for a linear solution that minimizes the deviations from the goodness functions [13]. In a different study, linear goal programming has been investigated to analyze the authenticity of the quota distribution using LINDO software [14]. Analysis results show that all the goals are over-achieved when they are allowed to interact simultaneously and not independently as in SOLP by using LGP method. In their study, Bassey and Effanga [15] reformulate the linear absolute regression problem as a LGP problem and they found that LGP method estimates the regression parameters better than the least squares method.

Utilization of the LGP technique is one of the popular methods for the transportation problems [16-20]. LGP is especially implemented in the area of public transportation planning area. As an example, a bus route optimization study for 185 buses with three different bus types in Kağıthane garage of Istanbul city was conducted by Alp [9]. His study demonstrated the utilization of objective functions with different weighted goal functions and with distinct time and duration constraints. By analyzing the results, Alp [9] emphasized the effectiveness LGP models. In a different study, Tekin et al. [21] provided that LGP method has an effective tool for the Schedule Optimization for the transportation studies. In his study, Deri [22] used smart card data in the public transport system in Izmir and used LGP and empirical correlation methods for the optimization of trip frequencies in 11 bus lines. From the comparison results, it was observed that the LGP method gave more accurate results in terms of eliminating the free capacity. In another study, Uludağ [23] implemented the LGP using capacity and duration constraints for 26 different public transportation routes in Izmır with different bus types. The study concluded that the LGP method can be used effectively in the calculation of the optimum number of trips for bus routes. As seen from the existing literature, the LGP method is used effectively in public transport planning.

In the scope of this study, the optimum numbers of the trips and frequencies were determined for 10 different bus routes (only privately operated) randomly selected in the Antalya city of Turkey by implementing the LGP methodology. Apart from the studies of the current literature, the proposed model also included the cyclic rotation of the buses and aimed to minimize the total operational costs by equalizing the total covered distances of each buses. The results of the proposed model indicated that the LGP methodology provided an efficient solution for determining the optimum number of trips and headways. The used method and results of the study also lead to public transportation planners to develop and operate an effective bus route. Additionally, this study shows that LGP method can be used an effective method for determining the optimum number of trips for bus routes. All these explained reasons, study findings have an important contribute to current literature.

2. DATA COLLECTION A ND ANALYSIS

Within the scope of this study, Antalya city, ranks the 5th populated city of Turkey (2.328,555 person for yer 2017) was selected. The factors which are effective for the selection of the public bus transport system of Antalya city can be summarized as follows:

- Most of the public transport system of the Antalya is based on buses.
- Mostly the use of a single bus type (solo buses).
- The complete utilization of the card system provides the determination of the exact number of passengers for each trip.

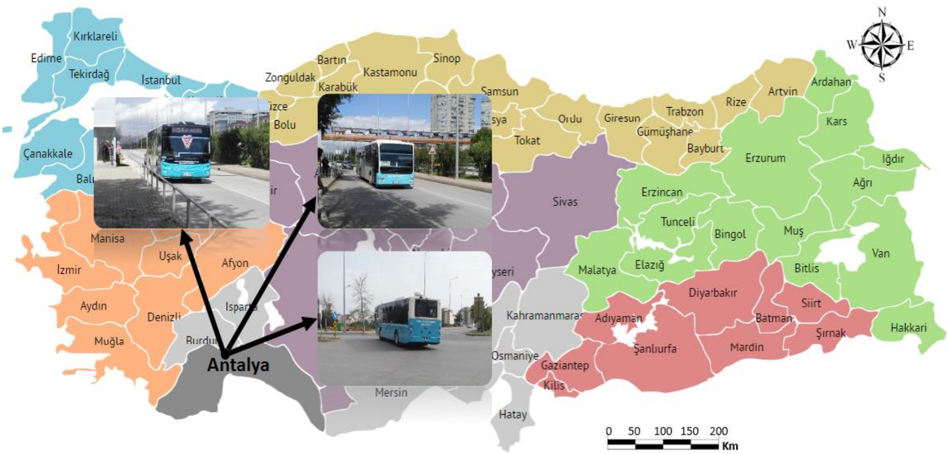
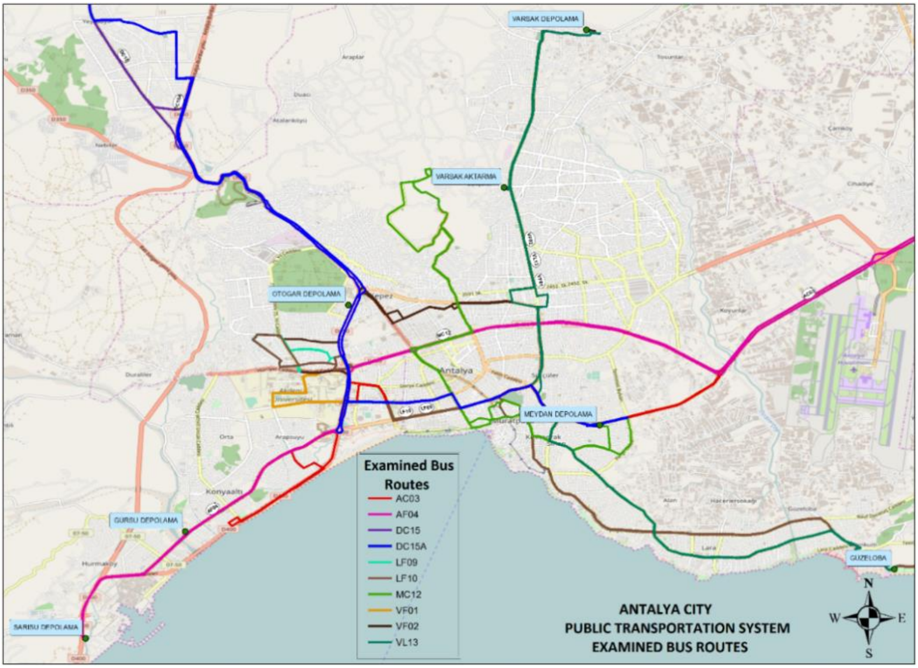
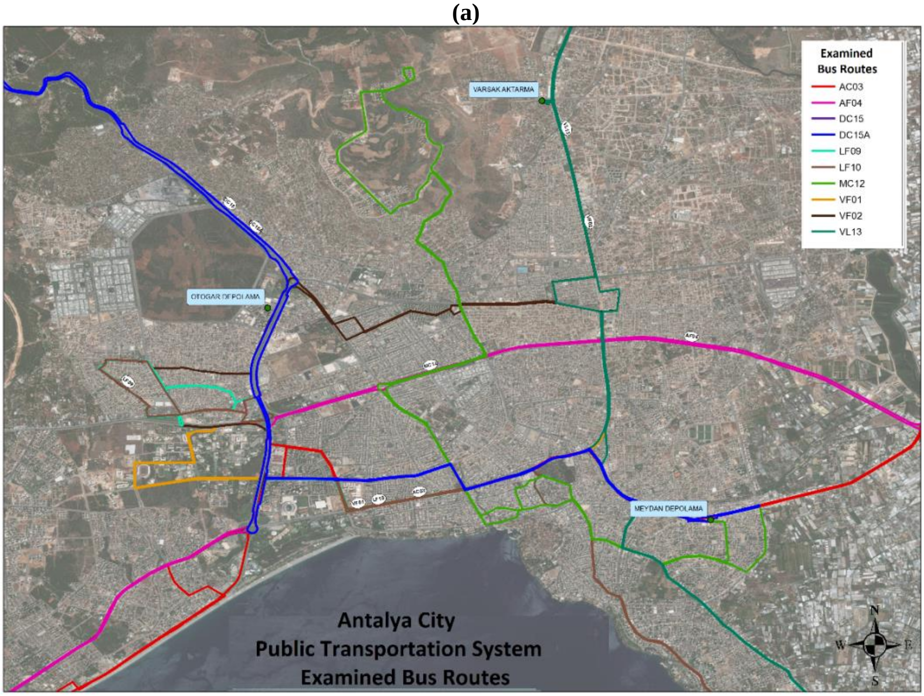


Figure 1. The location of the Antalya city and sample images of the existing bus routes.

In Antalya city, among the 97 different bus routes, only 10 privately operated and main public bus routes were selected (other 87 bus routes are operated by the Antalya Metropolitan Municipality Public Transit Department) for the analysis as shown in Figure 2.



(a)



(b)

Figure 2. a) Map and b) Satellite Images of the selected privately operated bus routes.

For the analysis, trip data were collected for the selected routes between 07:00 am and 10:00 am (daily 3 hours period) considering 165 operated buses. All data were collected by using the Automatic Bus Fare Collection (contactless smartcards) systems for the year 2016. Route informations, route lengths (including departure and arrival), Time-Capacity utilization ratio and average daily passenger numbers of the selected and examined routes can be summarized as given in Table 1.

Table 1. The collected data and typical characteristics of the 10 bus routes.

Input	Route Name	Route Definition	Route Length (Km)	Time-Capacity Utilization Ratio	Passenger Numbers (Person)
X_1	VF01	Varsak Depolama-100.Yıl Blv-Fakülte	47.7	0.72	3992
X_2	VF02	Varsak depolama-Sakarya Blv-Otogar-Sealife	51.2	0.78	2154
X_3	AC03	Aksu Depolama-Aspendos Blv-100.Yıl-Sealife	56.8	0.73	2761
X_4	AF04	Aksu Depolama-Gazi Blv-Sarısu	68.6	0.88	2103
X_5	LF09	Lara plaj-Barınaklar Blv-100.Yıl Blv-Gülveren	45.2	0.81	2986
X_6	LF10	Lara plaj-Bülent Ecevit Blv-100.Yıl Blv-Gülveren	44.5	0.81	2957
X_7	MC12	Meydan Depolama-D. Garajı-Gazi Blv-Mazı Dağı	33.9	0.66	1042
X_8	VL13	Varsak Depolama-Barınaklar Blv-Lara Plaj	50.3	0.98	1489
X_9	DC15	Meydan Depolama-Döşemealtı Atatürk Cd-Organize Sanayi	74.9	1.00	1088
X_{10}	DC15A	Meydan Depolama-Döşemealtı Atatürk Cd-Çıplaklı-Organize Sanayi	78.7	1.00	1218

While the model constraints were determined, it was considered that the bus frequencies and capacities meet the passenger demand on that particular route and also same daily trip lengths were considered for each buses. The principal constraint of the optimization model was that the average daily route length multiplied by the number of operated vehicles was set equal to the summation of the total trip distance of all vehicles while assuring the serviceability for all passengers (See Eq.1). The model constraints are summarized as follows:

$S_1, S_2, \dots \dots \dots \dots S_i$: Time frequency values for trips,
$C_1, C_2, \dots \dots \dots \dots C_i$: Capacity values of the bus type used in each route,
$K_1, K_2, \dots \dots \dots \dots K_i$: Passenger demand values in each route,
$D, D_2, \dots \dots \dots \dots D_i$: Length (km) values for each route.

$$S_i \times C_i \geq K_i \tag{1}$$

The constraints of the model were determined as trip constrain (S), capacity constraint (C), passenger demand constraint (K), and the length of the route (D) (km). Model constraints were considered to be of equal priority. The objective function of the model was described as the minimization of the negative deviation sum of the travel, capacity and route length constraints as shown in Eq. (2).

$$min\ S = d_1^- + d_2^- + d_3^- \tag{2}$$

Trip constraints were determined with the Eq. (3) by using the total number of operated buses.

$$N = \sum_{i=1}^{10} \frac{T_i}{\mathrm{T}} \times X_i - {d_1}^{+} + {d_1}^{-} \quad (3)$$

where:

N : Total number of operated buses,
T_i : Trip time for each bus route,
T : Total time (180 mins),
X_i : The required number of the trips for the i.th bus route,
T_i/T : The capacity utilization rate of the bus for each route.
Eq. (4) was used for calculating the total number of the buses.

$$165\ (C_1) = 0.7X_1 + 0.78X_2 + 0.76X_3 + 0.83X_4 + 0.8 + 0.81X_6 + 0.66X_7 + 0.98X_8 + 1X_9 + 1X_{10} - {d_1}^{+} + {d_1}^{-} \quad (4)$$

Capacity constraints were determined by using the passenger demand value (K) with Eq. (5).

$$\sum_{\mathrm{i}=1}^{10} K_i = \sum_{i=1}^{10} C_i \times X_i - {d_2}^{+} + {d_2}^{-} \quad (5)$$

where:

K_i : Passenger demand value for ith route,
C_i : Capacity value for the bus type used in the ith route,
X_i : The required number of trips for the ith route.

According to the analysis results, the equation describing the total passenger demand value was determined as Eq. (6).

$$21790\ (C_2) = 125X_1 + 125X_2 + 125X_3 + 125X_4 + 125X_5 + 125X_6 + 125X_7 + 125X_8 + 125X_9 + 125X_{10} - {d_2}^{+} + {d_2}^{-} \quad (6)$$

with the constrains shown as:

$$125X_1 \geq 3992\ (C_3)$$
$$125X_2 \geq 2154\ (C_4)$$
$$125X_3 \geq 2761\ (C_5)$$
$$125X_4 \geq 2103\ (C_6)$$
$$125X_5 \geq 2986\ (C_7)$$
$$125X_6 \geq 2957\ (C_8)$$
$$125X_7 \geq 1042\ (C_9)$$
$$125X_8 \geq 1489\ (C_{10})$$
$$125X_9 \geq 1088\ (C_{11})$$
$$125X_{10} \geq 1218\ (C_{12})$$

The operated buses in the selected routes are solo type buses with the length of 12 meters (Figure 3) [24]. While the technical capacity of the buses are 100 passengers, electronic passenger card records indicate that an average value of 125 passengers were carried during the trips. Considering this fact, the bus capacities were taken as 125 passengers in the model and this assumptions resulted relatively more realistic model outputs.

(a) **(b)**

Figure 3. (a) A real sample visual and (b) 2D representation of the buses used in public transportation in the city of Antalya [25].

Target distance (km) constraint was considered with the total distance traveled (km) using Eq. (7).

$$D_t \times O = \sum_{i=1}^{10} D_i \times X_i - {d_3}^+ + {d_3}^- \tag{7}$$

where:

D_i : Length of the ith route (km),
O : Number of available buses,
X_i : The required number of trips for the ith route,
D_t : The average distance (average Km) expected to be traveled per each vehicle.

$$9075(C_{13}) = 47.7X_1 + 51.2X_2 + 56.8X_3 + 68.6X_4 + 45.2X_5 + 44.5X_6 + 33.9X_7 + 50.3X_8 + 74.9X_9 + 78.7X_{10} - {d_2}^+ + {d_2}^- \tag{8}$$

In Antalya city public transport system, the average daily distance for all vehicles ($X_{avg.}$) as 275 km. The daily working hours was 15 and the average required distance in 180 minutes was determined as 55 km. In the prepared goal programming model, the data given in Table 2 were used in the lights of the above mentioned constraints. The analyzes were made with the help of WinQSB software. The model outputs are summarized as in Table 3. Particularly, the required trip numbers for each routes and the required trip intervals within the 3 hour periods were determined and summarized in Table 4.

Table 2. Model inputs.

Model Inputs	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	d_1^-	d_1^+	d_2^-	d_2^+	d_3^-	d_3^+	RHS
min(G_1)	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—
C_1	0.72	0.78	0.76	0.83	0.81	0.81	0.66	0.98	1	1	1	-1	—	—	—	—	165
C_2	125	125	125	125	125	125	125	125	125	125	—	—	1	-1	—	—	21790
C_3	125	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3992
C_4	—	125	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2154
C_5	—	—	125	—	—	—	—	—	—	—	—	—	—	—	—	—	2761
C_6	—	—	—	125	—	—	—	—	—	—	—	—	—	—	—	—	2103
C_7	—	—	—	—	125	—	—	—	—	—	—	—	—	—	—	—	2986
C_8	—	—	—	—	—	125	—	—	—	—	—	—	—	—	—	—	2957
C_9	—	—	—	—	—	—	125	—	—	—	—	—	—	—	—	—	1042
C_{10}	—	—	—	—	—	—	—	125	—	—	—	—	—	—	—	—	1489
C_{11}	—	—	—	—	—	—	—	—	125	—	—	—	—	—	—	—	1088
C_{12}	—	—	—	—	—	—	—	—	—	125	—	—	—	—	—	—	1218
C_{13}	47.7	51.2	56.8	68.6	45.2	44.5	33.9	50.3	74.9	78.7	—	—	—	—	1	-1	9075

Table 3. Results of the WinQSB model.

Variables	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	d_1^-	d_1^+	d_2^-	d_2^+	d_3^-	d_3^+
Solution Value	32	18	23	17	24	24	9	12	9	10	0	12.38	0	460	0	85.36
Unit cost	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0
Reduced Cost	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0
Constraints	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	—	—	—
Left Edge	165	21.79	4.00	2.25	2.88	2.125	3.00	3.00	1.13	1.50	1.13	1.25	9.08	—	—	—
Direction	=	=	≥	≥	≥	≥	≥	≥	≥	≥	≥	≥	=	—	—	—
Right Edge	165	21.79	3.99	2.15	2.76	2.10	2.99	2.96	1.04	1.49	1.09	1.22	9.08	—	—	—
Freedom or Excess	0	0	8	96	114	22	14	43	83	11	37	32	0	—	—	—

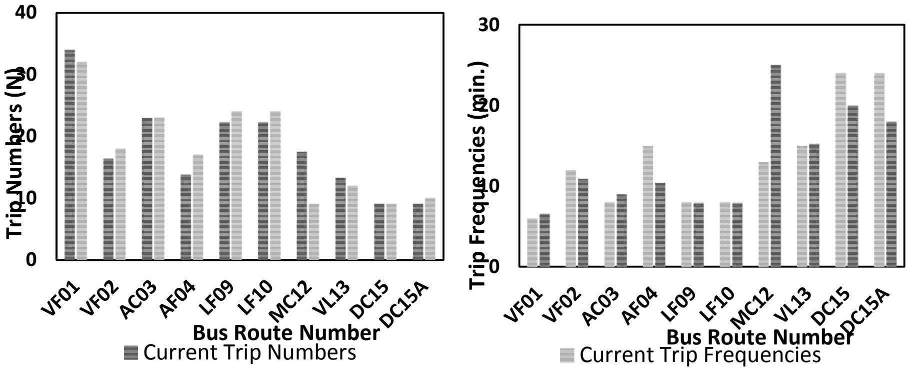
3. FINDINGS

As the given results of Table 4 are investigated for the passenger numbers, trip numbers for regular bus routes and trip numbers for balanced bus routes according to the required average distance. It is concluded that there exist increase in the trip numbers of some specific routes (VF02, AF04, LF09, LF10 and DC15A). In contrary, there exist decrease in other three other routes (VF01, MC12 and VL13). It is shown that the greatest increase in the number of the trips is experienced for the AF04 with a value of +3 and in contrary, the greatest decrease is experienced for route MC12 with a value of -9. When the frequencies of trips were examined, it was found that there was no change in LF09, LF10 and VL13 bus routes. However trip frequencies were increased for the routes of VF01, AC03 and MC12 and trip frequencies were decreased for the routes VF02, AF04, DC15 and DC15A. In the frequency of routes, the highest increase was observed in the MC12 bus route (+12) and the maximum decrease was in the DC15A bus route (-6). It is seen that although the travel values of the MC12 route are the lowest value among the all routes, the current number of trips was the lowest. Also if the DC15 and DC15A routes were compared with the MC12 route, while the travel values of these two routes were significantly higher, the trip frequency of the MC12 route was almost doubled the values of these two bus routes. Owing to the shorter distance of the MC12 route, trip intervals were kept as shorter for this particular route however, the implemented mode kept the trip number at lowest values by considering the passenger numbers in this particular bus route. The trip intervals were kept low in the present situation, but the applied model reduced the number of trips by considering the number of passengers on the route. In this way, the efficiency of the line has been increased.

Table 4. Comparison of the current situation of trip numbers and trip frequencies found by implementing the optimization model.

Bus Route Name	Current Trip Frequencies	Suggested Trip Frequencies	Variation* (Trip)	Current Trip Headways	Suggested Trip Headways	Variation* (Trip)
VF01	34	32	2 (↓)	6	7	1 (↑)
VF02	16	18	2 (↑)	12	11	1 (↓)
AC03	23	23	0 (=)	8	9	1 (↑)
AF04	14	17	3 (↑)	15	10	5 (↓)
LF09	22	24	2 (↑)	8	8	0 (=)
LF10	22	24	2 (↑)	8	8	0 (=)
MC12	18	9	9 (↓)	13	25	12 (↑)
VL13	13	12	1 (↓)	15	15	0 (=)
DC15	9	9	0 (=)	24	20	4 (↓)
DC15A	9	10	1 (↑)	24	18	6 (↓)

*****(=) no change in value (↑) increased value (↓) decreased value with respect to previous conditions.



(a) **(b)**

Figure 4. (a) The table between the current and proposed trip numbers, (b) The variations between the current and proposed trip frequencies.

As the Figure 4(a), Figure 4(b) and Table 4 were observed simultaneously, the model results indicated that, for the 50% of the bus routes, the trip numbers were increased while trip intervals were decreased. The phenomena is also valid for the opposite case as the decreased trip numbers for some specific bus routes were accompanied with the increased trip intervals. For the remaining 50% of the bus routes there were no evidences of any decrease or change in trip numbers. For some specific bus routes (LF09 and LF10), there were no increase in the route intervals while the trip numbers are increased. This latter phenomenon can be explained with the assignment of additional buses for the service of the passengers due to increased passenger density. Similar to the MC12 bus route, the observed low passenger demand was accompanied with the 50% decrease of the trip numbers and increasing of the trip intervals up to 20 minutes according to the proposed model. This condition cannot be justified as it can be thought as 20 minutes of waiting time is a psychological boundary for the desire of the passengers for a particular bus route. In conclusion, the model results can further be evaluated by taking the trip intervals as constant time for some particular bus routes with high passenger demands.

4. CONCLUSION

Within the scope of this study, 10 bus routes (only all private operated bus routes) were considered in the city center of Antalya and the Linear Goal Programming (LGP) method was used to determine the optimum number of vehicles to be operated on these routes and trip frequencies by evaluating the passengers demand on the peak hour of a day.

Apart from the studies of the current literature, the proposed model also included the cyclic rotation of the buses and aimed to minimize the total operational costs by equalizing the total covered distances of each buses. The results of the proposed model indicated that the LGP methodology provided an efficient solution for determining the optimum number of trips and headways. According to LGP model analysis, model results indicated that, for the 50% of the bus routes, the trip numbers were increased while trip intervals were decreased. The phenomena is also valid for the opposite case as the decreased trip numbers for some specific bus routes were accompanied with the increased trip intervals. For the remaining 50% of the bus routes there were no evidences of any decrease or change in trip numbers. These results show that LGP method has an effective tool for the effective schedule planning of bus transit routes.

The application of the above proposed LGP model for the entire public transport system may be compromised due to the increased number of lines and constraints. In this case, the LGP model may need to be made more readily available in terms of data input. For this purpose, with the development of a computer application, the changes in passenger number and route structure in the public transport system can be transferred to the models and the dynamic flight frequency and the vehicle numbers can be optimized and the continuous and accurate results can be achieved. In the following studies, an extensive model considering all the routes in the transportation network simultaneously can be used in the optimization of the trip frequencies and vehicle numbers to achieve a more efficiently operated public transportation network [26]. With considering the reliability of the trip frequencies taken from the model, the model constraints can further be evaluated. As a final note, study indicates that the implementation of the LGP model for the whole transportation system can be nontrivial due to the increased number of routes and accompanying constraints. A computer application can also be developed for assuring a and continuous optimization process for obtaining real time dynamic suggestion for the trip frequencies and vehicle numbers by considering the time variable passenger numbers and route characteristic.

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