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ESTIMATION OF PASSENGER-KILOMETER AND TONNE-KILOMETER VALUES FOR HIGHWAY TRANSPORTATION IN TURKEY USING THE FLOWER POLLINATION ALGORITHM

Summary. Within the scope of this study, intercity passenger and freight movements in Turkey are estimated by using the flower pollination algorithm (FPA), while demand forecasts are performed on transport systems considering possible future scenarios. Since the passenger and freight transport system in Turkey mainly involves road transport, passenger-kilometer and tonne-kilometer values of this system are estimated. By relying on three independent parameters, models were developed in three different forms: linear, force and semi-quadratic. Population (P) between 1990 and 2016, gross domestic product per capita (GDPperC) in US dollars and the number of vehicles were used as input parameters for the development of the models. When the passenger-kilometer models were created, the number of cars, buses and minibuses that are predominantly used for passenger transportation was preferred for the number of vehicles, while the number of trucks and vans used for cargo transportation were taken into consideration in the tonne-kilometer models. The coefficients of the models were determined by FPA optimization, with models developed to estimate passenger-kilometer and tonne-kilometer values. The model results were

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compared with the observation values and their performance was evaluated. Two different scenarios were created to estimate passenger-kilometer and tonne-kilometer in 2030. Parallel to the increase in population and welfare level, it is predicted that demand for passenger and freight transport will increase. In particular, the higher input parameter values in Scenario 1 significantly affect the increase in demand, leading to a demand increase of around 50%. In addition, the FPA has demonstrated effective performance in predicting the demand for passenger and freight transport and that it can be used in many different areas.

Keywords: passenger-kilometer, tonne-kilometer, flower pollination algorithm

1. INTRODUCTION

Transport, defined as the rapid, economic and secure displacement of people and goods, is a service activity created by other sectors of demand, with industry, commerce, agriculture and tourism among the most important sectors that generate demand. In the main, Turkey has a highway transport system, with approximately 90% of passenger and freight transport [1] carried out via this transportation system. The highway transportation system brings about many problems, especially traffic accidents. It is possible to obtain many benefits and to avoid transportation problems with the development of transportation systems with a specific plan for and the coordination of each transport system. For this purpose, it is necessary to determine future transportation demands in order to create the right plans and policies.

Many researchers have been working on forecasting transport demand for years. Different approaches have been applied to estimate the demand for passenger and freight transport, and more realistic models have been put forward. Garrido and Mahmassani [2] have applied the multinomial probit model with a spatially and temporally correlated error structure to estimate freight transport demand. The model has been successfully applied to the actual transport data set presented by a large truck load carrier. In addition to the substantive information obtained from the estimation results, the predictive tests were performed to assess the predictive ability of the model for operational purposes [11]. Haldenbilen and Ceylan [3] used socio-economic data and developed demand prediction models using genetic algorithms. They attempted to estimate freight and passenger movements in intercity roads in Turkey for the period up to 2025 by using the proposed models. Çelikoğlu and Cıgızoğlu [4] conducted an estimation of passenger flows with a generalized regression neural network and compared them with a stochastic model. It has been shown that the proposed model gives better results than observational results and performs better than the statistical model. Semeida [5] developed forecasting models for travel demand for less populated places in north-eastern Egypt with multiple linear regression and generalized linear modelling. Demand models can provide acceptable statistics within regions and are conceptually suitable. In addition, this study found that the generalized linear modelling approach is more appropriate and accurate than the regression approach. Nuzzolo and Comi [6] developed a model for predicting the demand for urban freight in Rome, depending on the quantity, delivery and vehicle. The developed modelling system is multistage and considers a separate selection approach for each decision level. The model has been tested using traffic counts and interviews with retailers and truck drivers in the inner area of Rome. Yang [7] developed demand prediction models for regional freight transport by applying simple linear regression, multiple linear regression and non-linear regression approaches. The latter approach outperformed others. Toole et al. [8] estimated travel demand using mobile phone call records in conjunction with

open and crowded geographical data, census records and surveys. The flexibility of the developed system has been analysed in various cities around the world.

The aim of this study is to develop simple and practical transportation demand forecasting models based on population, GDPperC and the number of vehicles. In addition, it seeks to demonstrate that the FPA, one of the artificial intelligence techniques, is applicable to the estimation of transportation demand.

2. FLOWER POLLINATION ALGORITHM

The FPA, developed by Xie-She Yang [9] in 2012, is inspired by the reproductive behaviour of flowering plants. The pollination method is used in the maintenance of optimal biological viability and reproduction. There are two important forms of pollination: biotic and abiotic. The biotic form, which takes place with pollens transferred by pollinators, such as flying insects, has been used in the reproduction of 90% of flower plants. The abiotic form, in which no pollinator is required, is used in 10% of plants. This model has been developed with certain assumptions and rules. The FPA has four basic rules and looks for the most appropriate solution according to these rules:

- The processes of global pollination are carried out in biotic form, while pollinators carry pollen in the form of cross-pollination according to Lévy flights.
- Abiotic pollination and self-pollination constitute local pollination.
- Pollinators can improve the reproduction probability of flower constancy, which is proportional to the similarity of the two flowers.
- Local and global pollution can be controlled by a switching probability $p \in [0,1]$.

Given that insects can fly for a long time, pollen can be transported over long distances. This situation guarantees the best reproduction possible. The mathematical expression of flower constancy is shown in Equation 1.

$$x^{t+1} = x_i^t + \gamma L(\lambda)(g_* - x_i^t) \tag{1}$$

where x_i^t is solution vector at iteration t and g_* is the current best. Here, γ is a scaling factor to control the step size.

The Lévy distribution is used to correspond to the strength of pollination. When insects travel long distances, the movement of insects can be represented by the Lévy distribution. Lévy’s mathematical expression is shown in Equation 2.

$$L \sim \frac{\lambda \Gamma(\lambda) \sin\left(\frac{\pi\lambda}{2}\right)}{\pi} \frac{1}{s^{1+\lambda}}, \quad (s \gg s_0 > 0) \tag{2}$$

where $\Gamma(\lambda)$ is the standard gamma function and s is the step size. This distribution is valid for “ $s > 0$ ” large steps. In theory, $s_0 > 0$ is required; but, in practice, s_0 can be as small as 0.1. For local pollination, both Rule 2 and Rule 3 are shown in Equation 3.

$$x^{t+1} = x_i^t + \epsilon(x_j^t - x_k^t) \tag{3}$$

where x_j^t and x_k^t are pollen from different flowers of the same plant species.

3. PASSENGER-KILOMETER AND TONNE-KILOMETER MODELS USING THE FLOWER POLLINATION ALGORITHM

Population (P), GDPperC and the number of vehicles (V) were used as input variables in the development of the models. These data were obtained from the Turkey Statistical Institute [10]. During the creation of the passenger-kilometer models, the number of cars, buses and minibuses that are generally used for passenger transportation were used for the number of vehicles, while the number of trucks and vans used for cargo transportation were taken into consideration in the tonne-kilometer models. Twenty-two of the 27-year-old input parameters between 1990 and 2016 were randomly divided and used as training data, while the rest were used as test data. The models developed in linear, force and semi-quadratic forms are shown in Equations 4-6.

Linear form:

$$Y_{km} = w_1 * x_1 + w_2 * x_2 + w_3 * x_3 + w_4 \quad (4)$$

Power form:

$$Y_{km} = w_1 * x_1^{w_2} * x_2^{w_3} * x_3^{w_4} \quad (5)$$

Semi-quadratic form:

$$Y_{km} = w_1 * x_1 + w_2 * x_2 + w_3 * x_3 + w_4 \sqrt{x_1 * x_2} + w_5 \sqrt{x_1 * x_3} + w_6 \sqrt{x_2 * x_3} + w_7 \quad (6)$$

Here, x_1 , x_2 and x_3 are population, GDPperC and the number of vehicles, respectively. w_i s are the coefficients of the models.

After the models were optimized according to the FPA, the coefficients of models were obtained, as shown in Table 1.

Tab. 1

Coefficients of the models		
Tonne-kilometer		
Linear	Power	Semi-quadratic
$w_1=10,185$	$w_1=0.097$	$w_1=9,979$
$w_2=3,429,856$	$w_2=1.336$	$w_2=-55,146,909$
$w_3=-11,231$	$w_3=-0.285$	$w_3=-175,884$
$w_4=-481,854,122,943$	$w_4=0.453$	$w_4=-282,809$
		$w_5=-5,588$
		$w_6=7,115,182$
		$w_7=-371,062,336,694$
Passenger-kilometer		
Linear	Power	Semi-quadratic
$w_1=5,747$	$w_1=0.335$	$w_1=-1,223$
$w_2=-832,688$	$w_2=1.299$	$w_2=-15,297,166$
$w_3=31,827$	$w_3=-0.036$	$w_3=-33,060$

w ₄ =394,859,379,208	w ₄ =0.256	w ₄ =-910,708
		w ₅ =1,255
		w ₆ =3,939,353
		w ₇ =363,813,728,095

4. FINDINGS AND EVALUATION

The performance evaluation of the proposed models was performed according to the mean absolute percentage error (MAPE) and the coefficient of determination (R²) methods. The mathematical expressions of the comparison criteria are given in Equations 7 and 8.

$$MAPE = 1/m \sum_{n=1}^m \left| \frac{Y_{Observed} - Y_{Estimated}}{Y_{Observed}} \right| \tag{7}$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^n (Y_{Observed} - Y_{estimated})^2}{\sum_{i=1}^n (Y_{Observed} - Y_{mean})^2} \right] \tag{8}$$

The statistical values of the passenger-kilometer and tonne-kilometer estimation models according to training and test data are given in Table 2.

Tab. 2

Statistics for training and test data

		Passenger-kilometer			Tonne-kilometer		
		Linear	Power	Semi-quadratic	Linear	Power	Semi-quadratic
Training	MAPE	4.1	6.64	3.09	6.18	8.15	5.57
	R²	96.17	91.29	97.74	95.87	92.47	96.53
Test	MAPE	4.36	8.81	3.7	6.07	9.28	6.26
	R²	95.98	92.42	97.74	97.39	95.06	97.29

When the results of the statistics given in Table 2 are analysed as training and test data, it is understood that the semi-quadratic model gives the best result in terms of MAPE and R² values and provides the closest estimate to the observation values with minimum error. In the passenger-kilometer forecast, the performance of the model was better than the tonne-kilometer forecast, and could be estimated with an average error of 3%. It has been shown that, although the performance of the linear model is worse than the semi-quadratic model, it can be an alternative method because it is a practical and useful form. The performance of the force model has been unsuccessful compared to other models, while it has been observed that the estimations of this form for the passenger-kilometer and the tonne-kilometer model are very different from the observation results with a 9% error.

5. PASSENGER-KILOMETER AND TONNE-KILOMETER PROJECTION

Passenger-kilometer and tonne-kilometer values for the future are estimated with two possible scenarios. In Scenario 1, the population is predicted to increase by 1.7% per year on average, and it is assumed that it will reach about 100 million in 2030. The increase in GDPperC is determined as 4% by considering the economic growth data for Turkey. The scenario is also set by assuming that vehicle numbers will increase by 3%. In Scenario 2, the projection of the Turkey Statistical Institute data has been used for population growth, with the population estimated to be approximately 89 million in 2030. The increase in GDPperC and the number of vehicles is determined by considering the 27-year growth rate. Thus, while the number of vehicles used for passenger transport in 2030 is approximately 19 million vehicles, it is predicted that the number of vehicles used for freight transport will be 5.5 million. Tables 3 and 4 show the projection values of the input parameters in Scenario I and Scenario II, respectively.

Tab. 3

Scenario I: input variable future forecast

Years	Future projection			
	Population	GDPperC	Number of vehicles for passengers	Number of vehicles for freight
2017	81,171,724	9,739	12,422,372	4,353,173
2018	82,551,643	10,128	12,857,155	4,440,237
2019	83,955,021	10,533	13,307,156	4,529,042
2020	85,382,256	10,955	13,772,906	4,619,622
2021	86,833,755	11,393	14,254,958	4,712,015
2022	88,309,929	11,848	14,753,881	4,806,255
2023	89,811,197	12,322	15,270,267	4,902,380
2024	91,337,988	12,815	15,804,727	5,000,428
2025	92,890,734	13,328	16,357,892	5,100,436
2026	94,469,876	1,3861	16,930,418	5,202,445
2027	96,075,864	14,415	17,522,983	5,306,494
2028	97,709,154	14,992	18,136,287	5,412,624
2029	99,370,209	15,592	18,771,057	5,520,876
2030	101,059,503	1,6215	19,428,044	5,631,294

Tab. 4

Scenario II: input variable future forecast

Years	Future projection			
	Population	GDPperC	Number of vehicles for passengers	Number of vehicles for freight
2017	80,550,000	10,670	12,087,653	4,127,815
2018	81,320,000	10,760	12,154,523	4,283,771
2019	82,080,000	10,853	12,753,633	4,439,727
2020	82,820,000	10,949	13,369,193	4,595,684
2021	83,540,000	11,050	14,001,201	4,751,640
2022	84,250,000	11,154	14,649,657	4,907,596
2023	84,940,000	11,263	15,314,562	5,063,552
2024	85,570,000	11,381	15,995,916	5,219,508

2025	86,180,000	11,504	16,693,718	5,375,465
2026	86,780,000	11,631	17,407,968	5,531,421
2027	87,350,000	11,762	18,138,668	5,687,377
2028	87,900,000	11,899	18,885,815	5,843,333
2029	88,430,000	12,040	19,649,412	5,999,289
2030	88,930,000	12,188	20,429,456	6,155,245

According to both scenarios, the passenger-kilometer and tom-km demand for the time period up to 2030 was forecasted using the semi-quadratic model, which offered the best performance. The distribution graph of these estimates is given in Figure 1.

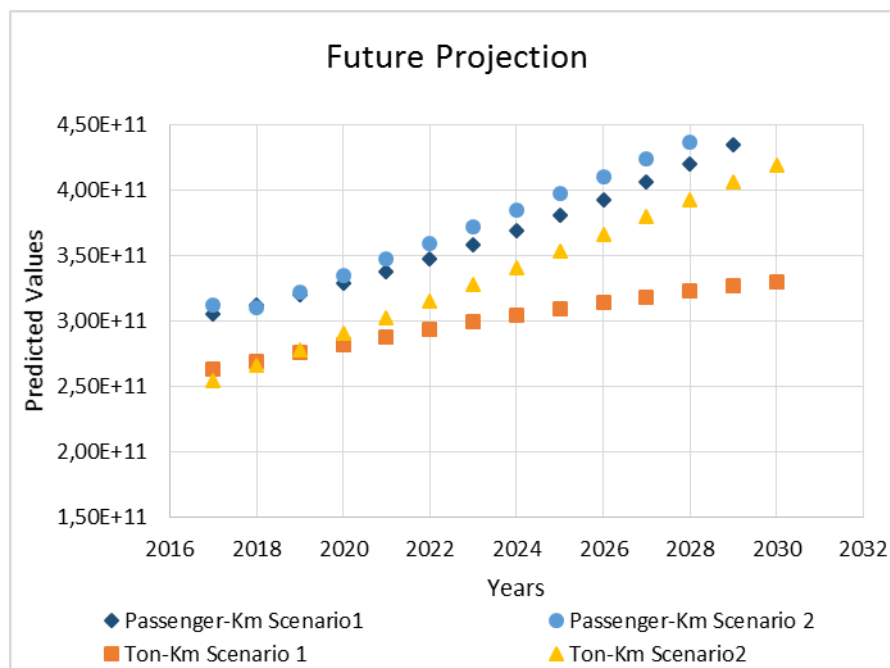


Fig. 1. Passenger-kilometer and tonne-kilometer prediction values

In the passenger-kilometer estimation, both scenarios showed parallel predictions, while the tonne-kilometer estimation was expected to show a different trend according to the scenario.

6. CONCLUSION

In this study, the applicability of the FPA for the estimation of passenger-kilometer and tonne-kilometer values in Turkey has been demonstrated. Three different forms of road passenger and freight demand forecasting models have been developed with statistical data covering 27 years, and the results are presented. The best performance has been observed with the semi-quadratic model, compared to other models. When looking at the simplicity and suitability of the forms, it can be seen that the linear model could be used as an effective alternative approach, even though it delivered worse results than the semi-quadratic model.

According to different scenarios, it is expected that the demand for passenger and freight transport will increase in parallel with an increase in the population and the level of prosperity. In particular, according to the input parameter values in Scenario 2, the increase in

freight and passenger demand is more than in the case of Scenario 1, while it is predicted that demand will increase by 50%. In addition, the rate of increase for trucks and pickups in Scenarios 1 and 2 is also reflected in the demand increase, and it is understood from the graph in Figure 1 that there is a linear relationship between them.

The FPA has demonstrated effective performance in predicting passenger and freight transport demand and that it can be used in many different areas. The effectiveness of the FPA approach will be highlighted in future studies by comparing it to other artificial intelligence techniques.

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