Research Journal of Applied Sciences, Engineering and Technology 5(2): 546-552, 2013
DOI:10.19026/rjaset.5.4987
ISSN: 2040-7459; E-ISSN: 2040-7467

Submitted: May 15, 2012 Accepted: June 08, 2012 Published: January 11, 2013

Research Article

Traffic Demand Forecast of Road in Kigali, Rwanda

[1]Zhang Chao, [2]Cao Peng and [1]Li Jianbo
[1]China Road and Bridge Corporation, C88 Zhonglu Plaza Andingmenwai Street, Beijing
[2]Department of Transportation Science and Engineering, Harbin Institute of Technology, Haihe Street, Nangang District, Harbin

Abstract: Accurate forecasting of traffic demand is one of the most important issues in the feasibility study on highway projects. The existing traffic forecasting models, to some extent, have the problem of limited accuracy. In this study, two widely used methods which are Elastic Coefficient Method (ECM) and Motorized Travel Frequency Method (MTFM) were comprehensively applied to forecast the traffic volume in Kigali, Rwanda. And Comparative analysis was made between the forecasting result and the actual survey traffic result in the project's future years. Compared with the actual survey result, the predicted result of ECM is larger and relative error is 10.49%. The result of MTFM is smaller and relative error is -7.11%. While the weighted average of above methods is closer to the actual result with a relative error in the interval of -5.00 to 5.00%. The research has shown that the combined forecast method proposed in this study, which can make up the defects in accuracy of single model, is easy to operate and owns more accuracy in traffic prediction. This study has suggested that proper combination of several methods would be an advisable trend for the traffic demand forecasting.

Keywords: Elastic coefficient method, motorized travel frequency method, traffic demand forecast

INTRODUCTION

Traffic forecast, an important stage in feasibility study of highway, is the foundation for construction scale and standard. Only on the premise of accurate prediction on the future traffic volume of highway project, can we make sense of economic analysis and social benefit evaluation of the project. Especially with diversification of highway construction financing, returning on investment becomes the biggest concern of the investors, hence it is very important to forecast traffic volume in the preliminary stage of highway construction (Hong, 2011; Huang and Lu, 2010).

Intensive studies have been carried out in the field of traffic forecast since 1960s and several of methods have been explored whose structures vary in the degree of sophistication and data requirement. These methodologies can be classified into several types, like, regression models (Brian *et al*., 2002; Kamarianakis and Prastacos, 2005), traffic time series models (Stathopoulos and Karlaftis, 2003; Skamris and Flyvbjerg, 1997), gravity models, Kalman state space filtering models (Hong *et al*., 2011; Jae *et al*., 2005), grey system models and rolling models (Liu and Ren, 1994; Dia, 2001) etc. Elasticity Coefficient Method (ECM) and Motorized Travel Frequency Method (MTFM) are typical in regression models. The economy and population factors, which are directly related to traffic volume, are taken into consideration in both methods. Due to their simple principle, they are widely used in the world (Schreckenberg *et al*., 2001). By analyzing relationship between transport index and national economic indicators and travel frequency, this study combined ECM and MTFM to forecast traffic demand of reconstruction project in Kigali, Rwanda and proposed a more effective and convenient method for traffic forecasting (Jae *et al*., 2005).

Traffic demand is a descendent and traffic growth rate is related to some trend-type indicators, such as the growth rates of industrial and agricultural production, gross social product and population, in the direct impacted areas affected by economic condition and social activities (Chrobok *et al*., 2006; Li and Lin, 2006). Therefore, we can seize the developing regular of traffic demand by analyzing the relationship between economy and social activities, with multiple mathematic methods, for instance, elasticity coefficient model, regression analysis and econometric analysis. ECM takes full account of correlation between economic growth level and growth of traffic demand and seizes traffic development trend at the macro (Zeng, 2006). Generally speaking, the more economically developed, the lower of requirements for traffic is, hence the smaller elasticity coefficient is; while the more economically backward, the greater potential requirement for traffic, so the bigger elastic coefficient

Corresponding Author: Zhang Chao, China Road and Bridge Corporation, C88 Zhonglu Plaza Andingmenwai Street, Beijing, Tel.: 86+451+15846586189

is. For one certain area, there is an urgent need for traffic in the recent period, elastic coefficient is big and gradually decreases in the succeeding period (Wang *et al*., 2010; Bell, 1983). Elasticity coefficient e can be calculated by following formula:

$$e = \frac{t}{f}$$

where,
t = Percentage of Transport Efficiency Change
f = Percentage of Economic Benefits Change

The determination of the elasticity coefficient value is the sticking point of ECM. Generally, the elasticity coefficient which is related with socio-economic development level as well as regional characteristics and development strategy can be determined synthetically by analyzing history, status quo and development trend of region. For feasibility study of highway project, it is too hard to get the statistics of different regions traffic travel, so regression analysis and expert evaluating method can be used to get elasticity coefficient. The main factors affecting elasticity coefficient are socio-economic indicators and transportation related indicators. So elasticity coefficient of vehicle travel is reckoned based on section traffic of major road, vehicle population, passenger, freight traffic and GDP (Chang *et al*., 2011; Zhang *et al*., 2007), as shown in following formula:

$$\ln(Q) = \alpha + \sum_{i=1}^{n} e_i \ln(x_i) + \varepsilon$$

where,
Q = Traffic volume
α = Adjustment factor in influenced area
x_i = Influence factors, e.g., travel cost, population density, Per capita income, etc.,
ε = Random error
e_i = Model parameter, i.e., elastic coefficient

$$e_i = \frac{\partial Q}{\partial X} \times \frac{X}{Q} = \frac{\partial \ln Q}{\partial \ln X}$$

MTFM predicts future traffic volume from two direct factors, namely, growth rate of population and vehicle travel (Hung and Hong, 2009). The method presumes traffic growth is in proportion to the growth rates of these two factors. It has three steps. Firstly, it forecasts the future population in Kigali; secondly, it considers development tendency of both all-traffic-mode travel frequency and proportion of trips using motor vehicle to all-traffic-mode trips to forecast the growth rate of motorized travel frequency based on survey or experience; thirdly, the traffic demand growth rate is calculated by the following formula:

$$r_t^i = (1 + r_p^i)(1 + r_f^i) - 1$$

where,
r_t^i = Traffic demand growth rate in Year *i* (%)
r_p^i = Population growth rate in Year *i* (%)
r_f^i = Growth rate of motor travel frequency in Year *I* (%)

This project includes 9 sections with most of them located in the downtown of Kigali city. The improvement of current roads should be able to meet the future traffic demand. As can be foreseen with the rapid economic development in Kigali as well as in Rwanda, the urbanization and motorization in Kigali will speed up simultaneously.

Since traffic demand is basically originated from the economic and social activities, the traffic demand forecast is based on the estimation for future economic development, population, city expansion etc. Two population growth scenarios and two GDP growth scenarios were analyzed using different growth rates under different assumptions.

Correspondingly, the traffic forecast also included 2 scenarios, those were, “Lower Traffic Scenario” and “Upper Traffic Scenario”. For the former scenario, the social-economic data of Lower Population Scenario and Lower GDP Scenario were adopted while for the latter one those of Upper Population Scenario and Upper GDP Scenario were adopted (Table 1 and 2).

The population-generated traffic demand was forecasted by two methodologies, i.e., Generation Rate Method and Traffic Intensity Method. The result of traffic demand forecast was achieved by aggregating both population-generated traffic demand and port-induced traffic demand.

The flowchart in Fig. 1 summarizes the framework for the traffic demand forecasting.

In this study, two widely used methods which are Elastic Coefficient Method (ECM) and Motorized Travel Frequency Method (MTFM) were comprehensively applied to forecast the traffic volume in Kigali, Rwanda. And Comparative analysis was made between the forecasting result and the actual

Table 1: Population growth scenarios

Lower population scenario:	The growth of population of Kigali will slow down under certain control by the government. It is assumed that the population of Kigali by 2025 accounts for 11% of Rwanda.
Upper population scenario:	The population of Kigali will grow in a relatively high speed. It is assumed that the population of Kigali by 2025 accounts for 13% of Rwanda.

Table 2: GDP growth scenarios

Lower GDP scenario:	It is assumed that the GDP per capita will grow slowly with a rate of 2.3 to 2.9% during 2007 to 2025 and the population of Kigali will increase following the Lower Population Scenario.
Upper GDP scenario:	It is assumed that the GDP per capita will grow rapidly with a rate of 3.3 to 3.8% during 2007 to 2025 and the population of Kigali will increase following the Lower Population Scenario.

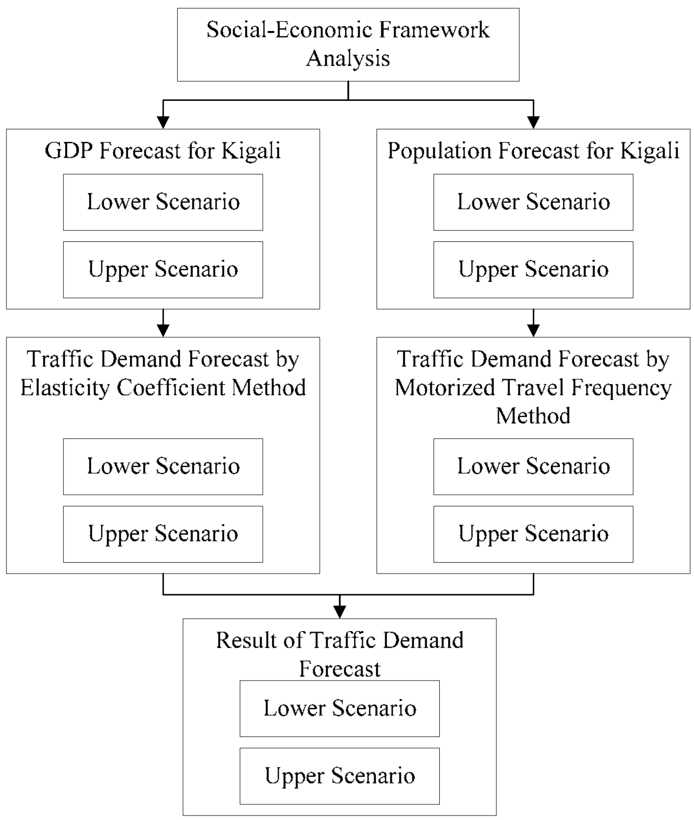

Fig. 1: Framework for traffic demand forecasting

survey traffic result in the project's future years. Compared with the actual survey result, the predicted result of ECM is larger and relative error is 10.49%. The result of MTFM is smaller and relative error is -7.11%. While the weighted average of above methods is closer to the actual result with a relative error in the interval of -5.00 to 5.00%. The research has shown that the combined forecast method proposed in this study, which can make up the defects in accuracy of single model, is easy to operate and owns more accuracy in traffic prediction. This study has suggested that proper combination of several methods would be an advisable trend for the traffic demand forecasting.

SOCIO-ECONOMIC FRAMEWORK

The socio-economic profiles of the areas were discussed in earlier sections of this study with detailed information included in Appendix. Based on the analysis on population growth trend, the population of Kigali was expected to grow at an average rate of 5.6% (Lower Population Scenario) or 6.5% (Upper Population Scenario) per annum during the period 2007 to 2010 and expected to slow down in the succeeding years (Table 3).

The GDP of Kigali was expected to grow rapidly and continuously, at an average rate of 8.0% (Lower GDP Scenario) or 10.0% (Upper GDP Scenario) per annum

Table 3: Estimated population growth of kigali

Period	2007-2010 (%)	2010-2015 (%)	2015-2024 (%)
Lower population scenario	5.6	4.2	3.0
Upper population scenario	6.5	5.0	4.0

Table 4: Estimated growth rate of GDP/GDP per capita of kigali

Period	2007-2010 (%)	2010-2015 (%)	2015-2024 (%)
Lower GDP scenario	8.0	7.0	6.0
Upper GDP scenario	10.0	9.0	8.0

during the period 2007 to 2010 and expected to slow down to 6.0% (Lower GDP Scenario) or 8.0% (Upper GDP Scenario) by 2024.

The GDP per capita of Kigali was expected to increase continuously, at an average rate of 0.9% (Lower GDP Scenario) or 2.8% (Upper GDP Scenario) per annum during the period 2007 to 2010 and expected to increase further to 2.9% (Lower GDP Scenario) or 4.8% (Upper GDP Scenario) by 2024 with the economic efficiency being improved gradually in the future (Table 4).

Detailed data of population and GDP forecast are shown in Table 1a and 2a in Appendix.

CURRENT TRAFFIC DEMAND OF THE EXISTING ROAD

A survey on the traffic volumes of the existing roads was conducted. The current traffic volume of each road section is shown in Table 5.

Traffic demand forecast:

Elasticity coefficient method: Social-economic activity is the root for traffic to occur and develop and the progress of social-economy will also be promoted by development of traffic. ECM is based on this assumption; it forecasts the future value of elasticity coefficient and determines the traffic demand in future on the basis of analyzing the development trend of future productivity and property structure.

Future traffic demand can be forecasted, adopting ECM, by formula as below:

$$r_t = e \times r_g$$

where,

r_t = Growth rate of traffic demand (%)

e = Elastic coefficient

r_g = Growth rate of economy, this report adopted GDP growth rate (%)

In the light of general experience in various cities and with consideration of the current traffic situation in Kigali, the values of elastic coefficient of this project are as below:

Based on the forecast of GDP growth rate in Kigali, with the elasticity coefficient in Table 6, the traffic demand growth rate of this project could be calculated. The results are shown in Table 3a in Appendix.

According to current traffic volume and the formula as follow, we could forecast the traffic volume in next few years:

$$T^{i} = T^{i-1} \times (1 + r_t^{i})$$

where,

r_t^i = Traffic growth rate in Year i

T^i = Traffic volume in Year i

The brief results are shown in Table 7.

In this study, average traffic demand of the project means the weighted average traffic volume calculated by the following formula:

$$T = \frac{\sum_j T_j L_j}{\sum_j L_j}$$

Table 5: Current traffic volume of the existing road

Road no.	Road name	Annual average daily traffic (pcu/day)
1	Avenue justice-nyamirambo	1724
2	Avenue de la gendarmerie	1668
3	Novotel-king Faysal hospital	1427
4	Aeorport-Hop. kanombe	1319
5	Avenue du lac muhazi	1818
6	Boulevard de l'umuganda	1766
7	Avenue des ministres et descente de la primature vers le sud	1423
8	Riepa-primature	1314
9	Obk-mamans sportives	1276

Table 6: Elasticity coefficient

Period	2007-2010	2010-2015	2015-2024
Elasticity Coefficient	1.10	1.0	0.80

Table 7: Average traffic demand of the project by elasticity coefficient method (pcu/day)

Year	Lower traffic scenario	Upper traffic scenario
2010	2.138	2.317
2015	2.999	3.565
2020	3.792	4.861
2025	4.793	6.629

Table 8: Average traffic demand of the project by motorized travel frequency method (pcu/day)

Year	Lower traffic scenario	Upper traffic scenario
2010	1.948	2.015
2015	2.517	2.705
2020	3.140	3.542
2025	4.000	4.735

where,

T = Average traffic demand of the project
T_j = Traffic volume of road section *j*
L_j = Length of road section *j*

Motorized travel frequency method: According to general experience in various cities and with consideration of the current income level and traffic situation in Kigali, the motorized travel frequency is taken as 0.8 at 2006 and gradually increased to 1.0 in 2024.

According to forecast result of the population growth rate in next few years, with the formula and coefficient, we could calculate the traffic demand growth rate of this project. The results are shown in Table 4a in Appendix.

Gone upon current traffic and the formula as follow, we could forecast traffic volume of every road section of this project:

$$T^{i} = T^{i-1} \times (1 + r_t^{i})$$

where,

r_t^i = Traffic growth rate in Year i
T^i = Traffic volume in year i

The brief results are shown in Table 8.

RESULT AND ANALYSIS OF TRAFFIC DEMAND FORECAST

The final results of traffic demand forecast are determined as the weighted average of ECM and MTFM results by formula as below:

$$A_i = A_{ie}\rho_e + A_{im}\rho_m,$$
$$\rho_e + \rho_m = 1.0$$

where,

A_i = Predicted traffic volume in year i
A_{ie}, A_{im} = Results of ECM and MTFM in year i
ρ_e, ρ_m = Weights, in this study, $\rho_e = \rho_m = 0.5$

The author investigated traffic volume of this project in 2010 and the result is evaluated by relative error RE_i (Table 9), calculated by formula as follow:

$$RE_i = \frac{A_i - B_i}{B_i} \times 100\%$$

where,

RE_i = Relative error of forecasted traffic volume in year i (%)
B_i = Actual survey traffic volume in year i

As can be seen from Table 9, the result of ECM was bigger than actual traffic volume, relative error is as large as 10.49%, while the result of MTFM, which ignored economic development, is smaller, relative error -7.11%. This may be because the increment in population and travel requirement lagged behind

Table 9: Result of traffic forecast of the project (pcu/day)

Year	Forecast results: Lower traffic scenario	Forecast results: Higher traffic scenario	Actual survey results	Relative error RE (%): Elasticity coefficient method: Lower traffic scenario	Elasticity coefficient method: Upper traffic scenario	Motorized travel frequency method: Lower traffic scenario	Motorized travel frequency method: Upper traffic scenario	Weighted average: Lower traffic scenario	Weighted average: Upper traffic scenario
2010	2.043	2.166	2.097	1.96	10.49	-7.11	-3.91	-2.58	3.29
2015	2.758	3.135	-	-	-	-	-	-	-
2020	3.466	4.202	-	-	-	-	-	-	-
2025	4.396	5.682	-	-	-	-	-	-	-

Appendix: Table 1a: Kigali population forecast

Year	Lower population scenario ('000)	Upper population scenario ('000)
2010	1.091	1.129
2015	1.340	1.441
2020	1.554	1.753
2025	1.801	2.132

Table 2a: Kigali GDP forecast

	Lower GDP scenario		Upper GDP scenario	
Year	(Billion Frw)	(Million US$)	(Billion Frw)	(Million US$)
2010	417.000	744.000	448.000	800.000
2015	584.000	1.043	690.000	1.231
2020	782.000	1.396	1.014	1.809
2025	1.046	1.868	1.489	2.659

Table 3a: Traffic growth rate by elasticity coefficient method

		Lower traffic scenario		Upper traffic scenario	
Year	Elasticity coefficient	GDP growth rate under lower GDP scenario (%)	Traffic growth rate (%)	GDP growth rate under upper GDP scenario (%)	Traffic growth rate (%)
2010	1.10	8.0	8.8	10.0	11.0
2015	1.00	7.0	7.0	9.0	9.0
2020	0.80	6.0	4.8	8.0	6.4
2025	0.80	6.0	4.8	8.0	6.4

Table 4a: Traffic growth rate by motorized travel frequency method

			Lower traffic scenario		Upper traffic scenario	
Year	Growth rate of motorized travel frequency (%)	Motorized travel frequency	Population growth rate under lower GDP scenario (%)	Traffic growth rate (%)	Population growth rate under upper GDP scenario (%)	Traffic growth rate (%)
2010	0.8	0.82	5.6	6.4	6.5	7.4
2015	1.2	0.86	4.2	5.5	5.0	6.3
2020	1.6	0.93	3.0	4.6	4.0	5.7
2025	2.1	1.02	3.0	5.2	4.0	6.2

economic development. The relative errors of both methods are larger. The weighted average of two methods, which takes account of influence of economic and population, is more accurate than each of them with a relative error in the internal of -5.00 to 5.00%. It is easy to operate as well as compensating shortage of a single method to combined ECM and MTFM. This points out that the proper combination of several methods should be one of the developmental trends for the traffic demand forecasting. More research is encouraged to analyze the relationship between weight distribution and economic development as well as travel frequency in follow-up study so that the results obtained in this study can be generalized further.

CONCLUSION

This study analyzes two widely used methods which are Elastic Coefficient Method (ECM) and Motorized Travel Frequency Method (MTFM) was comprehensively applied to forecast the traffic volume in Kigali, Rwanda. And Comparative analysis was made between the forecasting result and the actual survey traffic result in the project's future years. Compared with the actual survey result, the predicted result of ECM is larger and relative error is 10.49%. The result of MTFM is smaller and relative error is -7.11%. While the weighted average of above methods is closer to the actual result with a relative error in the interval of -5.00 to 5.00%. The research has shown that the combined forecast method proposed in this study, which can make up the defects in accuracy of single model, is easy to operate and owns more accuracy in traffic prediction. This study has suggested that proper combination of several methods would be an advisable trend for the traffic demand forecasting.

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