9th International Congress on Advances in Civil Engineering, 27-30 September 2010
Karadeniz Technical University, Trabzon, Turkey

Analyses of CO_2 Emissions Based on Estimated Transport Demand

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Abstract

The transport sector remains one of the main sources of CO_2 emissions in worldwide. Transport activity and resulting CO_2 emissions increase significantly especially in developing countries along with economic growth and rapidly increase of population. Therefore, future CO_2 emissions from transport sector should be determined in order to assess the amount of emissions whether it is under the critical limits proposed by Kyoto protocol and to implement CO_2 mitigation policies for sustainable environment. In this study, Harmony Search (HS) algorithm is used to estimate Turkey's transport demand based on socio-economic indicators such as Gross Domestic Product, Population and number of vehicles. For this purpose, HArmony Search Transport Demand Models (HASTDM) are developed such as linear, exponential and quadratic forms of mathematical expressions. The exponential model which is the best-fit model to the observed data is selected for future projection of Turkey's transport demand. The objective function for the model solution is to minimize the sum of squared error (SSE) between the observed and predicted values for each form. The amount of CO_2 emissions are determined based on projected transport demand using HS algorithm. As a result the factors that directly affect the transport demand are analyzed. It is shown that CO_2 emissions related to transport sector can be easily obtained based on estimated transport demand. The results showed that it is essential the investigation of CO_2 emissions based on transport demand for more sustainable environment and transport.

Keywords: *CO_2 emissions, transport demand, harmony search algorithm*

1 Introduction

The fast growth rate of world population and the industrial development have resulted in environmental problems like increase on green house gases and global warming. Recent evidence indicates that road traffic emissions are one of the major sources of air pollution. Although improvements in vehicle technology play a significant role in reducing traffic emissions at the source, air pollution abatement will remain a challenge for scientists , planners and engineers because demand for transportation continues to increase (WBCSD, 2001). Increase on the overall vehicle-kilometers over the past two decades has outweighed any gains in emission reductions achieved through advances in car technologies (Anderson et al., 1996; Potoglou and Kanaroglou, 2005). There is a growing emphasis on global effects, especially for greenhouse gases and notably CO_2. Road vehicles are acknowledged to be significant sources of a range of pollutants and they have been estimated to contribute around 10% of the total global, and 20% of the European anthropogenic CO_2 emissions (Metz, 2001). The estimation and modeling of CO_2 can be a powerful tool for air quality managers and environmentalists in order to examine the impact of different transport plans. In addition to this use, there is a growing need to examine how overall emissions of CO_2 can be managed by local transport management, in order to reduce its impact as a greenhouse gas.

Power, industry and transport are the three major sectors responsible for fossil-fuel-related CO_2 emissions in each country in the world. While the factors affecting CO_2 emissions and emission intensities of the industry and power sectors have been analyzed in many countries, transport sector emissions and emission intensities have not been examined to the same extent, especially in developing countries (Timilsina and Shrestha, 2009). Nevertheless, a few studies also examine factors affecting transport sector emissions growth. For example, Lakshmanan and Han (1997) attribute the change in transport sector CO_2 emissions in the US between 1970 and 1991 to growth in people's propensity to travel, population, and gross domestic product. Lu et al. (2007) decompose changes in CO_2 emissions from highway vehicles in Germany, Japan, South Korea and Taiwan during 1990–2002 into changes in emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity and economic growth. Understanding the factors affecting the growth of CO_2 emissions from the transport sector is critical because of its increasing prominence as a source of emissions in most countries and its relevance to the preparation of climate change mitigation strategies.

In this study, estimation of transport demand (veh-km/year) is carried out using population, gross domestic product and number of vehicles using Harmony Search (HS) algorithm. In this purpose, Harmony Search Transport Demand Models (HASTDM) are developed with three forms of mathematical expressions. Then, the sectoral CO_2 emissions are modeled with the HS using the projected transport demand. The paper is organized as follows. Data evaluation is defined in the next section. Section 3 is about the HS algorithm and the model development. Forecasting transport demand and CO_2 emission is given in Section 4 and 5, respectively. Last section is about the conclusions.

2 Data Evaluation

The Gross Domestic Product (GDP) and the population are collected from the Central Bank of Turkey (CBT) (2008) and the National Statistics (NS) (2008). Observed veh-km and the number of vehicles are taken from the General Directorate of Turkish Highways (GDTH) (2008). The observed trend of number of vehicles, GDP, population and veh-km between 1980 and 2008 can be seen in Figure 1 fixed at 1980 values. During the HASTDM modeling process, each form of the model is validated using the available data partly for use in estimating the weighting factors and partly for the testing purposes. The first 20 years observed data from 1980 to 1999 are used for estimating the weighting factors and the 9 years data from 2000 to 2008 are used for testing. The testing procedure is carried out to obtain the minimum relative errors between the observed and estimated values in the period of testing.

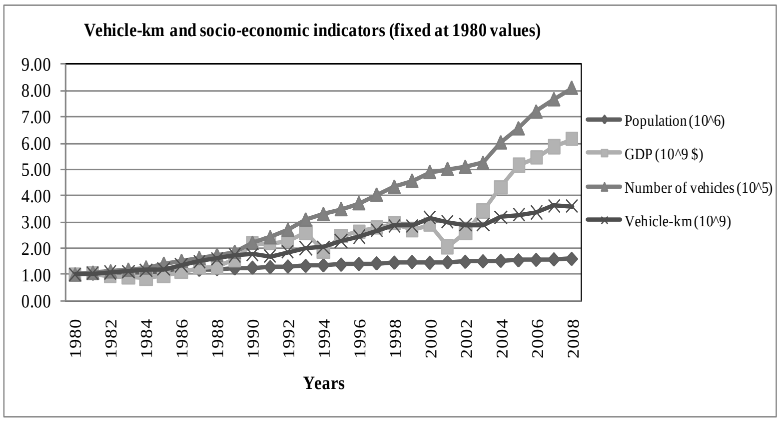

Figure 1. Used data for estimating Turkey's transport demand.

In Turkey, when the CO_2 emissions resulting from fuel consumption were examined, CO_2 emissions were 71 million tones in 1980, 223.81 million tones in 2000, 256.43 million tones in 2005 and CO_2 emissions reached 320.45 million tones in 2008 (NS, 2008; Special Report on Petroleum Products for Turkey (SRPP), 2000). When CO_2 emissions are analyzed according to contributors, 25 % energy, 34 % industrial, 19 % transport and 22% from other sectors caused CO_2 emissions in 1990. CO_2 emissions rates from transport sector were 19% in 1990, 19% in 1995, 15% in 2000, 16% in 2005 and 16% in 2008 (NS, 2008). An average rate CO_2 emission from transport sector in Turkey between 1990 and 2008 according to available data is about 17% from the total CO_2 emissions. Therefore, for future estimation of CO_2 emission, the data is used that obtained from the total CO_2 emission using average rate for transport sector. The used data for CO_2 emissions is given in Fig. 2.

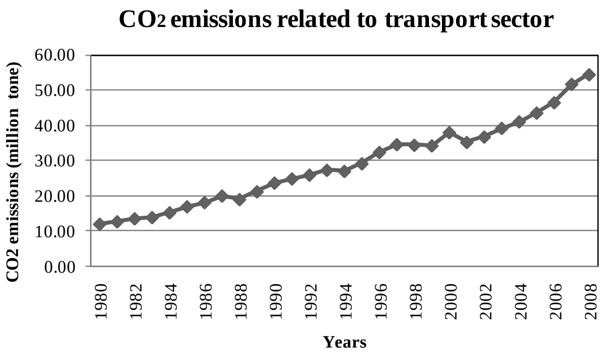

Figure 2. CO_2 emissions based on transport sector in Turkey.

3 Harmony Search and Model Development

The HS algorithm proposed by Geem et al. (2001) is a metaheuristic optimization algorithm and is based on the musical process of searching for a perfect state of harmony, such as jazz improvization. In this improvization process, members of the musical group try to find the best harmony as determined by an aesthetic standard, just as the optimization algorithm tries to find the global optimum as determined by the objective function. The notes and the pitches getting played by the individual instruments determine the aesthetic quality, just as the objective function value is determined by the values assigned to design variables. The harmony quality is enhanced with practice, just as the solution quality is enhanced with iteration (Geem, 2006). The basic flowchart of the HS algorithm is given in Fig. 3. The definition of the HS algorithm and its solution procedures may be obtained in Ceylan et al. (2008)

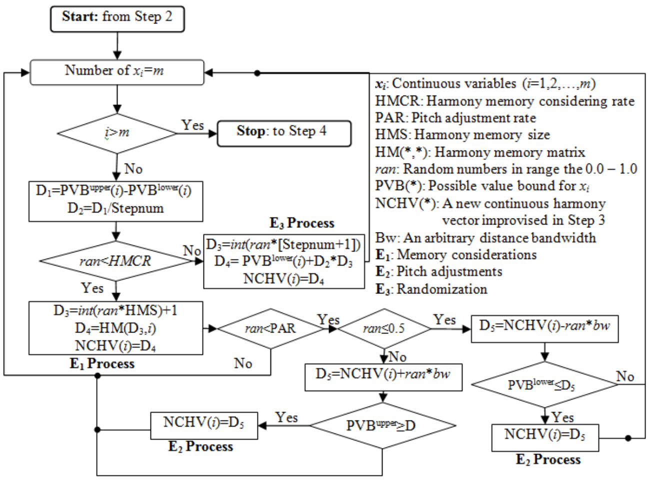

Figure 3. The flowchart of HS algorithm (Ceylan et al., 2008).

Models which are obtained using HASTDM include three parameters: GDP, population and veh-km. The estimation of Turkey's transport demand (TD) using three mathematical forms is given as follows.

$$f(x)_{linear} = w_1 X_1 + w_2 X_2 + w_3 X_3 + w_4 \tag{1}$$

$$f(x)_{\exp} = w_1 X_1^{w_2} + w_3 X_2^{w_4} + w_5 X_3^{w_6} + w_7 \tag{2}$$

$$f(x)_{quad} = w_1 X_1 + w_2 X_2 + w_3 X_3 + w_4 X_1 X_2 + w_5 X_1 X_3 + w_6 X_2 X_3 + w_7 \tag{3}$$

where $f(x)_{linear}$, $f(x)_{\exp}$ and $f(x)_{quad}$ are linear, exponential and quadratic forms of HASTDM models, respectively and X_1, X_2 and X_3 are the population (10^6), GDP(10^9\$) and the number of vehicles (10^5), respectively, $w_i \in W_i\,(i = 1,2,3,\ldots..,n)$ are the corresponding weighting factors and *n* is the number of decision variables that changes from one model to another. The objective function, *F*, to be minimized is

$$Min\ F = \sum_{i=1}^{m} (TD_{observed} - TD_{predicted})^2 \qquad (4)$$

where $TD_{observed}$ and $TD_{predicted}$ are the observed and predicted TD, *m* is the number of observations.

4 Forecasting Turkey's Transport Demand

For estimating Turkey's transport demand using HASTDM model, population, GDP and the number of vehicles needs to be estimated. Then, the future transport demand can be forecasted. The estimation of socio-economic and transport related indicators is performed in the following way.
For the population,

$$y = 0.9644x + 45.163 \qquad R^2 = 0.98 \qquad (5)$$

where *y* is the population in 10^6/year, and *x* is the time series (1980=1, 1981=2.........2008=29)
For the annual GDP,

$$y = 0.4678x^2 - 2.6606x + 78.948 \qquad R^2 = 0.89 \qquad (6)$$

where *y* is the GDP in 10^9\$/year, and *x* is the time series (1980=1, 1981=2.........2008=29)
For the number of vehicles,

$$y = 0.1146x^2 + 0.7455x + 15.598 \qquad R^2 = 0.99 \qquad (7)$$

where *y* is the number of vehicles in 10^5/year, and *x* is the time series (1980=1, 1981=2.........2008=29)
Three forms of the HASTDM model are given as following:
Linear form of the HASTDM model is;

$$f(x)_{linear} = 0.1977X_1 + 0.0484X_2 + 0.2142X_3 - 0.4680$$

$$F = 54.68 \qquad R^2 = 0.97 \qquad (8)$$

Exponential form of the HASTDM model is;

$$f(x)_{\exp} = 0.8757X_1^{0.5012} + 0.1570X_2^{0.2440} + 0.7128X_3^{0.8680} + 0.1353 \quad F = 38.44 \qquad R^2 = 0.97 \qquad (9)$$

Quadratic form of the HASTDM model is;

$$f(x)_{quad} = 0.4462X_1 - 0.0033X_2 - 1.1440X_3 + 0.000001X_1X_2 + 0.02X_1X_3 + 0.000001X_2X_3 - 1.0478$$

$$F = 23.86 \qquad R^2 = 0.98 \qquad (10)$$

where *F* is the final values of objective function given in (4) and R^2 is the correlation coefficient for each equation. The comparisons of the HASTDM outputs and their relative errors in the testing period are given for the period of 2000–2008 in Table 1. The relative errors based on the observed values for each HASTDM are compared. The relative errors obtained for example in 2005 is about 19%, 11% and 22% for linear, exponential, quadratic forms of the HASTDM models, respectively. Although the lowest value of objective function and highest R^2 values in the observation period is in the quadratic form of the HASTDM models, exponential form gives lowest relative error in the testing period as shown in Table 1.

Table 1. Comparing the three forms of the HASTDM for the testing period.

Years	Vehicle-km (10^9)	$f(x)_{linear}$	Relative error (%)	$f(x)_{exp}$	Relative error (%)	$f(x)_{quad}$	Relative error (%)
2000	44.22	39.97	0.10	40.89	0.08	40.36	0.09
2001	41.92	37.79	0.10	41.59	0.01	42.69	0.02
2002	40.50	40.03	0.01	42.12	0.04	44.67	0.10
2003	40.51	43.52	0.07	43.06	0.06	46.85	0.16
2004	44.33	49.59	0.12	47.66	0.08	51.54	0.16
2005	45.82	54.53	0.19	50.77	0.11	55.67	0.22
2006	47.06	58.02	0.23	54.39	0.16	60.71	0.29
2007	50.46	61.31	0.22	57.05	0.13	65.24	0.29
2008	50.26	64.04	0.27	59.51	0.18	69.94	0.39
Mean absolute error			*0.15*		*0.09*		*0.19*

Future estimation of the three forms of the HASTDM is shown in Fig. 4. The all forms of the HASTDM model estimate the transport demand according to obtained weighting parameters. Linear, exponential and quadratic forms of the HASTDM model estimate about a value of 97, 98 and 211 million tone at the year of 2020, respectively. The linear and exponential forms of models, which provide very close estimation results to each other and they underestimate the transport demand when they are compared with the projection of quadratic form. Exponential form of the HASTDM model is chosen as the best-fit model for forecasting transport demand so as it gives lowest relative error in the testing period, as shown in Table 1.

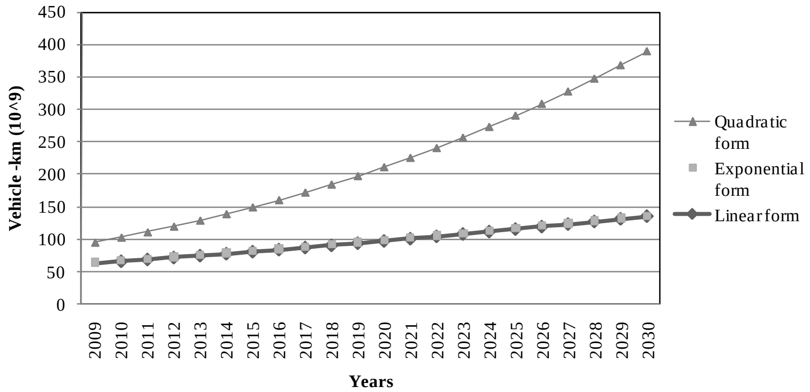

Fig. 4. Future estimations of transport demand using the HASTDM.

5 Forecasting CO_2 Emissions Based On Projected Transport Demand

The CO_2 emissions resulting from the transport sector for Turkey are projected based on transport demand using Eq. (11). The objective function for the solution is to minimize SSE between the observed and predicted values for CO_2 emissions.

$$f(x) = w_1 X^{w_2} \tag{11}$$

where $f(x)$ is CO_2 emissions, X is the veh-km (10^9), $w_i \in W_i \, (i = 1,2,3,\ldots\ldots n)$ are the corresponding weighting factors and n is the number of decision variables. The weighting factors are carried out using HS algorithm and are given as follows:

$$f(x) = 0.9585 X^{0.9888}$$

$$F = 36.94 \qquad R^2 = 0.98 \tag{12}$$

The future estimations for CO_2 emissions resulting from the transport sector for Turkey based on projected transport demand are given in Fig. (5).

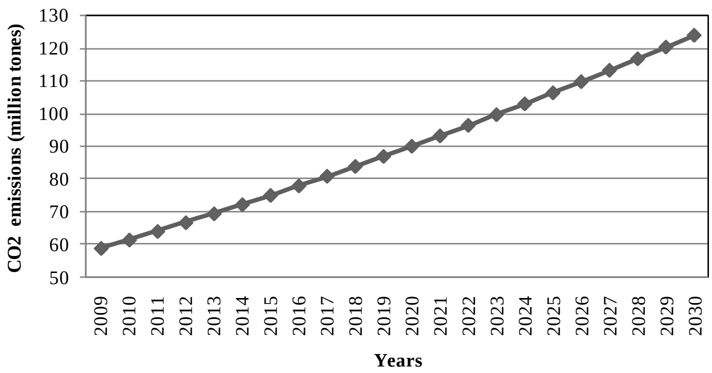

Fig. 5. Future estimations for CO_2 emissions.

As shown in Fig. 5, the future CO_2 emissions resulting from the transport sector have reached about to 75, 90 and 125 million tone in 2015, 2020, 2030, respectively. Thus, the CO_2 emissions per capita with respect to projected population for Turkey may be obtained about 0.89, 1.00 and 1.22 million tone at the same years. The CO_2 emissions resulting from the transport sector in European Union (EU) will be reached to 4.65 million tone per capita at the year 2020 (Baumert et al., 2005). Furthermore, the expected value of the CO_2 emissions resulting from transport sector in Turkey is estimated to 1.00 and 1.22 million tone per capita based on projected demand at the years 2020 and 2030, respectively. It is clear that the projected CO_2 emissions from transport sector in Turkey in 2030 are considerably less than the value that it is estimated in EU for the year 2020.

Although the future CO_2 emissions resulting from the transport sector in Turkey are less than the EU's projections, Turkey, as a developing country, is a responsible for CO_2 mitigation policies to control the CO_2 emissions based on transport sector. Furthermore, Turkish government should take into account that case during the process of Kyoto protocol which forced the countries to implement the CO_2 mitigation policies and to fight the global warming.

6 Conclusions

In this study, HS algorithm is used to estimate Turkey's transport demand based on socio-economic indicators such as Gross Domestic Product, Population and number of vehicles. For this purpose, HASTDM is developed such as linear, exponential and quadratic forms of mathematical expressions. The linear and exponential forms of models, which provide very close estimation results to each other and they underestimate the transport demand when they are compared with the projection of quadratic form. Exponential form of the HASTDM model is chosen as the best-fit model for forecasting transport demand so as it gives lowest relative error in the testing period. The amount of CO_2 emissions are determined based on projected transport demand using HS algorithm. According to results, the future CO_2 emissions resulting from the transport sector have reached about to 75, 90 and 125 million tone in 2015, 2020, 2030, respectively. Thus, the CO_2 emissions per capita with respect to projected population for Turkey may be obtained about 0.89, 1.00 and 1.22 million tone at the same years. As a result the factors that directly affect the transport demand are analyzed. It is shown that CO_2 emissions related to transport sector can be easily obtained based on estimated transport demand. The results showed that it is also essential the investigation of CO_2 emissions based on transport demand for more sustainable environment and carrying on the process of Kyoto protocol in accordance with the benefits of Turkey.

References

Anderson, W.P., Kanaroglou, P.S. and Miller, E.J. (1996). Urban form, energy and the environment: A review of issues, evidence and policy. *Urban Studies*. Vol. 33, pp. 7-35.

Baumert, K.A., Herzog, T. and Pershing, J. (2005). Navigating the Numbers, Greenhouse Gas Data and International Climate Policy. World Resources Institute.

Central Bank of Turkey (CBT). (2008). Available on-line at /http://www.tcmb.gov.tr, (in Turkish).

Ceylan, H., Ceylan, H., Haldenbilen, S. and Baskan, O. (2008). Transport energy modeling with meta-heuristic harmony search algorithm, an application to Turkey. *Energy Policy*. Vol. 36, pp. 2527-2535.

Geem, Z.W., Kim, J.H. and Loganathan, G.V. (2001). A new heuristic optimization algorithm: harmony search. *Simulation*. Vol. 76, 2, pp. 60-68.

Geem, Z.W. (2006). Optimal cost design of water distribution networks using harmony search. *Engineering Optimization*. Vol. 38, 3, pp. 259-280.

GDTH, General Directorate of Turkish Highways. (2008). Annual Statistics of Turkish Highways, http//.www.kgm.gov.tr, (in Turkish).

Lakshmanan,T. and Han, X. (1997). Factors underlying transportation CO2 emissions in the USA: a decomposition analysis. *Transportation Research Part D*., Vol. 2, 1, pp. 1-15.

Lu,I.J., Lin,S.J. and Lewis,C. (2007). Decomposition and decoupling effects of carbon dioxide emission from highway transportation in Taiwan, Germany, Japan and South Korea. *Energy Policy*. Vol. 35, 6, pp. 3226-3235.

Metz N. (2001). Contribution of passenger cars and trucks. *Proceeding of the environmental sustainability conference & exhibition*, November, Graz, Austria.

National Statistics (NS). (2008). Available on-line at http://www.tuik.gov.tr, (in Turkish).

Potoglou, D. and Kanaroglou, P. S. (2005). Carbon monoxide emissions from passenger vehicles: predictive mapping with an application to Hamilton, Canada. *Transportation Research*, 10D, pp. 97–109.

SRPP, Special Report on Petroleum Products for Turkey. (2000). VIII. National Development Plan, National Planning Department, Ankara, Turkey, (in Turkish).

WBCSD, World Business Council for Sustainable Development, Mobility. (2001). World Mobility at the end of the Twentieth Century and its Sustainability. Geneva.

Timilsina, G.R. and Shrestha, A. (2009). Transport sector CO2 emissions growth in Asia: Underlying factors and policy options. *Energy Policy*. Vol. 37, pp. 4523-4539.