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Research Note

Design of a Mathematical Model to Minimize Air Pollution Caused by Job Trips in Mega Cities

M. Abbaspour[1,*], T. Dana[2], M. Shafiepour[3] and M. Mahmoudi[4]

Abstract. *Urban transportation is one of the main sources of air pollution in mega cities, and urban job related trips can effectively influence the state of air quality. Tehran, the capital of Iran, with a population of 7.3 million, was selected for this study. The present model is designed to investigate the effect on traffic of the business working hours of different occupations and, as a result, on the status of air pollution. Daily job, non-job and recreational trips using the present vehicle fleet is a major factor affecting air pollution in Tehran. In the context of the present study, the necessary information was utilized to define some relations between job trips and pollutant emissions. The result showed that a proper adjustment of opening hours for different jobs can result in a reduction of pollutant emissions by as much as 20% during daily traffic peak hours.*

Keywords: *Mathematical model; Air pollution; Job trips; Traffic control measures.*

INTRODUCTION

Tehran, with a population of 7.3 million and over 1.18 million trips per one day peak hour at the same peak time, covers an area of 730 km^2 and is divided into 22 municipality districts or 560 traffic zones, as shown in Figure 1 [1].

The population growth in Tehran from anomalous immigration and the lack of an appropriate plan to control its unsustainable growth, has led to heavy traffic jams and an increase in air pollution.

The morning and evening traffic, which coincide with the opening and closing hours of most occupations, can be regarded as a major cause of public health problems and financial damage.

The report of Tehran's short term comprehensive transportation and traffic studies for the year 2000 indicated that development in the traffic network is unlikely to improve the state of air quality.

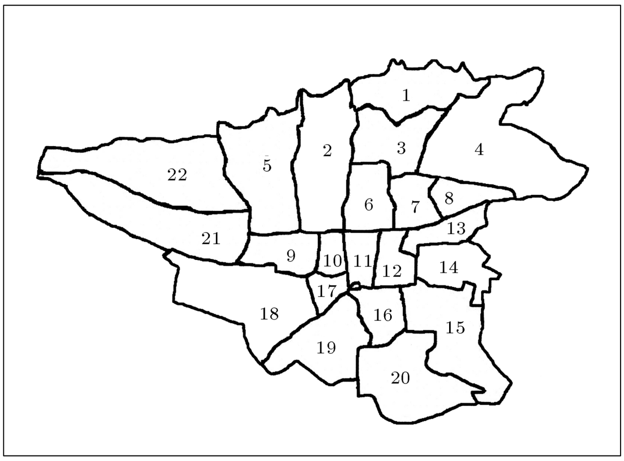

Figure 1. Tehran municipality districts as the understudy traffic areas.

The present situation proves the failure of this plan, due to the unsustainable development of residential areas and high rate of immigration.

MATERIALS AND METHODS

Given the number of factors influencing the rate of air pollution, multiple-regressions were used to establish an air pollution model by means of SPSS software.

The influence of each parameter, as an independent variable, on the rate of pollutant emissions,

1. *Department of Mechanical Engineering, Sharif University of Technology, Tehran, P.O. Box 11155-9567, Iran.*
2. *School of Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran.*
3. *Faculty of Envionment, University of Tehran, Tehran, Iran.*
4. *Department of BIO Statistics, School of Public Health and Institute of Health Research Center, University of Tehran Medical Sciences, Tehran, Iran.*
*. *Corresponding author. E-mail: m-abbaspour@jamejam.net*

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has been evaluated using multiple-regression analysis.

This sensitivity analysis has provided a proper management tool for Tehran's transportation system.

Statistical Traffic Databank

The most time-consuming step in this study was the collection of the data needed to conduct the analysis. The availability and quality of local data is crucial for obtaining reliable results.

Even though these relations can be used for Tehran's traffic situations, the methodology can also be utilized for other geographic regions. This, so called, Origin-Destination (O/D) method using demographic, socio-economic and trip related data, can help to build up the desired relations [2].

The databases used for this series of simulations were derived from Tehran Comprehensive Transportation and Traffic Studies (TCTTS), at the request of the Traffic and Transportation Organization (TTO). This project is comprised of 7 sub-projects including:

1. Tehran's traffic and transportation under the study area designation and zoning [3];
2. Land use models (population and employment) [4];
3. Trip production and attraction models [5];
4. Estimated models of car ownership per person;
5. Tehran's network database [5];
6. Trip distribution model, modal split model and assignment model [5];
7. Transportation technology and related study forecasting for year 2012 [5].

On this basis, the annual origin and destination databases were established, based on 560 traffic zones [6].

These databases were developed in accordance with the population growth rate of the year 2000. However, given the great influence of two factors (i.e. population and employment) in the formation of inner-city trips, it is possible to estimate the number of created trips within the studied zones. In the context of the present study, it was necessary to have access to the data on these trips for creating the statistics of daily job trips in Tehran. The statistical traffic databank of the year 2000 for Tehran was used for this purpose and daily job trip distribution within different travel times was calculated.

Multiple Regression Data Entry (Variables)

Using collected data on Tehran residents' trips in the study area, by all types of vehicle from every origin to every destination,the daily trips were classified into two main groups, i.e. job, non-job and recreational trips.

The following variables were defined, in order to define the related relations:

1. Laborers and farmers. This variable is shown as **J1** in the model equations.
2. Public Employees. This variable is shown as **J2** in equations.
3. Drivers. This variable is shown as **J3** in the model equations.
4. Teachers. This variable is shown as **J4** in the model equation.
5. Army Personnel. This variable is shown as **J5** in the model equations.
6. Private Sector. This variable is shown as **J6** in the model equations.
7. Non-Job and Recreational Trips. This variable is shown as **NJ** in the model equations.
8. Trip. This parameter indicates the ratio of the vehicle trip from every origin to destination zone divided by the population number of the origins. This variable is illustrated in the model as movement and is shown as **MO** in models.
9. Passenger Kilometers Traveled. The number of kilometers traveled by passengers within different districts of Tehran was entered into the software, measured as kilometers traveled by each passenger and called the passenger kilometer traveled. This variable is shown as **PK** in the model equations.
10. Emitted Pollutants by Mobile Sources. Previous studies have shown that pollutant emissions from vehicle fleets are the main source of air pollution in Tehran.

    The selected pollutant substances were CH_4, NO_2, CO, SO_2, PM_{10}, NMVOC (Non-Methane Volatile Organic Compound) and THC (Total Hydrocarbon) [7-9].
11. Hours (HR). The **HR** is considered as the most important variable for controlling all other variables in the designed model. The value of **HR** in this model was chosen by defined codes; i.e. code 1 for the time 0-4 A.M., code 2 for 4-5 A.M. and code 3 for 5-6 A.M., etc.

RESULTS AND DISCUSSIONS

Multiple Linear Regression Models to Evaluate Emission of Pollutants

In order to assess the multiple regression air pollution models, different parameters were defined and entered into SPSS software. The corresponding results are shown in Equations 1 to 7, followed by Tables 1 to 7 [10]:

$$\mathbf{CH_4} \text{ (tons per day)} = 5.378^*10^{-4} - 4.63^*10^{-5}\mathbf{HR} + 3.891^*10^{-4}\mathbf{J1} + 4.283^*10^{-4}\mathbf{J2} + 1.372^*10^{-4}\mathbf{J3} + 2.363^*10^{-4}\mathbf{J5} + 3.552^*10^{-4}\mathbf{J6} + 6.454^*10^{-4}\mathbf{NJ} + 4.870^*10^{-7}\mathbf{PK} + 2.062^*10^{-8}\mathbf{MO}, \quad (1)$$

$$\mathbf{NO_2} \text{ (tons per day)} = -2.89^*10^{-4} + 1.06^*10^{-4}\mathbf{HR} + 7.353^*10^{-4}\mathbf{J1} + 1.43^*10^{-3}5\mathbf{J2} + 7.491^*10^{-4}\mathbf{J3} + 4.516^*10^{-4}\mathbf{J5} + 3.655^*10^{-3}\mathbf{J6} + 3.655^*10^{-3}\mathbf{NJ} + 3.77^*10^{-6}\mathbf{PK} + 1.886^*10^{-7}\mathbf{MO}, \quad (2)$$

$$\mathbf{CO} \text{ (tons per day)} = -4.23^*10^{-3} + 6.432^*10^{-4}\mathbf{HR} + 1.305^*10^{-2}\mathbf{J1} + 2.476^*10^{-3}\mathbf{J2} + 7.298^*10^{-3}\mathbf{J3} + 7.524^*10^{-3}\mathbf{J5} + 4.702^*10^{-2}\mathbf{J6} + 5.226^*10^{-2}\mathbf{NJ} + 6.716^*10^{-5}\mathbf{PK} + 1.257^*10^{-5}\mathbf{MO}, \quad (3)$$

$$\mathbf{SO_2} \text{ (tons per day)} = -3.89^*10^{-4} + 3738^*10^{-5}\mathbf{HR} + 6.137^*10^{-5}\mathbf{J1} + 3.235^*10^{-4}\mathbf{J2} + 4.056^*10^{-5}\mathbf{J3} + 1.079^*10^{-4}\mathbf{J5} + 2.4^*10^{-4}\mathbf{J6} + 5.85^*10^{-4}\mathbf{NJ} + 6.479^*10^{-7}\mathbf{P} - 7.48^*10^{-8}\mathbf{M}, \quad (4)$$

$$\mathbf{PM_{10}} \text{ (tons per day)} = -6.44^*10^{-5} + 8.797^*10^{-6}\mathbf{HR} + 1.443^*10^{-4}\mathbf{J1} + 2.738^*10^{-4}\mathbf{J2} + 9.043^*10^{-5}\mathbf{J3} + 9.462^*10^{-5}\mathbf{J5} + 5.393^*10^{-4}\mathbf{J6} + 6.463^*10^{-4}\mathbf{NJ} + 7.529^*10^{-7}\mathbf{PK} + 9.282^*10^{-8}\mathbf{MO}, \quad (5)$$

$$\mathbf{NMVOC} \text{ (tons per day)} = -2.76^*10^{-4} + 4.838^*10^{-5}\mathbf{HR} + 1.184^*10^{-3}\mathbf{J1} + 2.241^*10^{-3}\mathbf{J2} + 6.674^*10^{-4}\mathbf{J3} + 7.706^*10^{-4}\mathbf{J5} + 4.039^*10^{-3}\mathbf{J6} + 4.728^*10^{-3}\mathbf{NJ} + 5.898^*10^{-6}\mathbf{PK} + 1.232^*10^{-6}\mathbf{MO}, \quad (6)$$

$$\mathbf{THC} \text{ (tons per day)} = -3.31^*10^{-4} + 5.516^*10^{-5}\mathbf{HR} + 1.268^*10^{-3}\mathbf{J1} + 2.409^*10^{-3}\mathbf{J2} + 7.147^*10^{-4}\mathbf{J3} + 8.482^*10^{-4}\mathbf{J5} + 4.325^*10^{-3}\mathbf{J6} + 5101^*10^{-3}\mathbf{NJ} + 6.405^*10^{-6}\mathbf{PK} + 1.305^*10^{-6}\mathbf{MO}. \quad (7)$$

Following these findings, in order to assess the multiple regression air pollution model during morning traffic peak hours, the mentioned parameters were entered into SPSS software, focusing on a limited time period between 5:00 AM-8:00 AM, in order to find job-trips which affect morning peak air pollution. The corresponding results are shown in Equations 8-14:

$$\mathbf{CH_4} \text{ (tons per morning peak hours)} = 0.0289 - 6.27^*10^{-3}\mathbf{HR} + 6.322^*10^{-6}\mathbf{PK} + 2.192^*10^{-3}\mathbf{NJ} - 4.57^*10^{-3}\mathbf{J4} - 3.16^*10^{-3}\mathbf{J3} - 2.17^*10^{-3}\mathbf{J6} - 1.8^*10^{-3}\mathbf{J5}, \quad (8)$$

$$\mathbf{NO_2} \text{ (tons per morning peak hours)} = 2.909^*10^{-2} + 3.349^*10^{-6}\mathbf{PK} - 6.08^*10^{-3}\mathbf{HR} + 3.107^*10^{-3}\mathbf{NJ} - 4.25^*10^{-3}\mathbf{J4} - 3.23^*10^{-3}\mathbf{J3} - 2.41^*10^{-3}\mathbf{J6} - 1.7^*10^{-3}\mathbf{J5}, \quad (9)$$

Table 1. Parameters influencing methane emission (tons/day): Coefficients[a].

Model	Unstandardized Coefficients	Standardized Coefficients	*t*
	B	Beta	
(Constant)	5.378E-04		9.948
HR	-4.63E-05	-0.64	-16.794
J1	3.891E-04	0.031	6.194
J2	4.283E-04	0.034	6.799
J3	1.372E-04	0.011	2.185
J5	2.363E-04	0.019	3.762
J6	3.552E-04	0.029	5.611
NJ	6.454E-04	0.052	9.541
PK	4.870E-07	0.342	79.387
MO	2.062E-08	0.000	0.104

a: Dependent variable: CH_4, $R^2 = 0.135$,
Standard error for estimate: 0.0040453188.

Table 2. Parameters influencing nitrogen dioxide emission (tons/day): Coefficients[a].

Model	Unstandardized Coefficients	Standardized Coefficients	*t*
	B	Beta	
(Constant)	-9.89E-04		-6.904
HR	1.060E-04	0.040	14.508
J1	7.357E-04	0.016	4.418
J2	1.435E-03	0.031	8.591
J3	4.791E-04	0.010	2.877
J5	4.516E-04	0.010	2.712
JOB6	3.265E-03	0.071	19.451
NJ	3.655E-03	0.079	20.383
PK	3.770E-06	0.711	231.757
MO	1.886E-07	0.001	0.359

a. Dependent variable: NO_{-}, $R^2 = 0.560$,
Standard error for estimate: 0.0107253749.

Table 3. Parameters influencing carbon monoxide emission (tons/day): Coefficients[a].

Model	Unstandardized Coefficients	Standardized Coefficients	*t*
	B	Beta	
(Constant)	-4.23E-03		-1.727
HR	6.432E-04	0.014	5.154
J1	1.305E-02	0.016	4.589
J2	2.476E-02	0.031	8.679
J3	7.298E-03	0.009	2.566
J5	7.524E-03	0.009	2.645
J6	4.702E-02	0.059	16.398
NJ	5.226E-02	0.065	17.059
PK	6.716E-05	0.729	241.743
MO	1.257E-05	0.004	1.399

a: Dependent variable: CO, $R^2 = 0.575$,
Standard error for estimate: 0.1832024423.

Table 4. Parameters influencing sulfur dioxide emission (tons/day): Coefficients[a].

Model	Unstandardized Coefficients	Standardized Coefficients	*t*
	B	Beta	
(Constant)	-3.84E-04		-7.584
HR	3.738E-05	0.052	14.475
J1	6.137E-05	0.005	1.043
J2	3.235E-04	0.026	5.480
J3	4.056E-05	0.003	0.689
J5	1.079E-04	0.009	1.834
J6	2.400E-04	0.019	4.044
NJ	5.850E-04	0.047	9.230
PK	6.479E-07	0.458	112.689
MO	-7.48E-08	-0.001	-0.402

a: Dependent variable: SO_2, $R^2 = 0.230$,
Standard error for estimate: 0.0037910531.

Table 5. Parameters influencing PM_{10} emission (tons/day): Coefficients[a].

Model	Unstandardized Coefficients	Standardized Coefficients	*t*
	B	Beta	
(Constant)	-6.44E-05		-2.549
HR	8.797E-06	0.017	6.827
J1	1.443E-04	0.017	4.912
J2	2.738E-04	0.031	9.293
J3	9.043E-05	0.010	3.079
J5	9.462E-05	0.011	3.221
J6	5.343E-04	0.061	18.044
NJ	6.463E-04	0.074	20.432
PK	7.524E-07	0.752	262.288
MO	9.282E-08	0.003	1.000

a: Dependent variable: PM_{10}, $R^2 = 0.616$,
Standard error for estimate: 0.0018917004.

Table 6. Parameters influencing non-methane volatile organic compound emission (tons/day): Coefficients[a].

Model	Unstandardized Coefficients	Standardized Coefficients	*t*
	B	Beta	
(Constant)	-2.76E-04		-1.339
HR	4.838E-05	0.012	4.598
J1	1.184E-03	0.017	4.938
J2	2.241E-03	0.032	9.319
J3	6.674E-04	0.010	2.783
J5	7.760E-04	0.011	3.236
J6	4.039E-03	0.058	16.710
NJ	4.728E-03	0.068	18.310
PK	5.898E-06	0.742	251.829
MO	1.232E-06	0.004	1.627

a: Dependent variable: NMVOC, $R^2 = 0.595$,
Standard error for estimate: 0.0154431218.

Table 7. Parameters influencing total hydrocarbon emission (tons/day): Coefficients[a].

Model	Unstandardized Coefficients	Standardized Coefficients	t
	B	Beta	
(Constant)	-3.31E-04		-1.500
HR	5.516E-05	0.013	4.902
J1	1.268E-03	0.017	4.942
J2	2.409E-03	0.032	9.367
J3	7.147E-04	0.010	2.787
J5	8.482E-04	0.011	3.307
J6	4.325E-03	0.058	16.731
NJ	5.101E-03	0.068	18.471
PK	6.405E-06	0.746	255.696
MO	1.305E-06	0.004	1.611

a: Dependent variable: THC, $R^2 = 0.602$,
Standard error for estimate: 0.0165167236.

$$\mathbf{CO}\ \text{(tons per morning peak hours)} = -0.582 + 7.3^{*}10^{-5}\mathbf{PK} - 0.137\mathbf{HR} + 0.157\mathbf{NJ} + 0.865\mathbf{J2} + 6.45^{*}10^{-2}\mathbf{J1} + 3.77^{*}10^{-2}\mathbf{J5}, \quad (10)$$

$$\mathbf{SO_2}\ \text{(tons per morning peak hours)} = 2.163^{*}10^{-3} + 2.228^{*}10^{-7}\mathbf{PK} - 4.94^{*}10^{-4}\mathbf{HR} + 4.786^{*}10^{-4}\mathbf{NJ} + 2.34^{*}10^{-4}\mathbf{J2} + 1.706^{*}10^{-4}\mathbf{J1} - 1.4^{*}10^{-4}\mathbf{J4}, \quad (11)$$

$$\mathbf{PM_{10}}\ \text{(tons per morning peak hours)} = 6.181^{*}10^{-3} + 7.224^{*}10^{-7}\mathbf{PK} - 1.43^{*}10^{-3}\mathbf{HR} + 1.49^{*}10^{-3}\mathbf{NJ} + 7.805^{*}10^{-4}\mathbf{J2} + 5.867^{*}10^{-4}\mathbf{J1} - 3.05^{*}10^{-4}\mathbf{J4} + 2.858^{*}10^{-4}\mathbf{J5}, \quad (12)$$

$$\mathbf{NMVOC}\ \text{(tons per morning peak hours)} = 0.05971 + 6.15^{*}10^{-6}\mathbf{PK} - 1.32^{*}10^{-2}\mathbf{HR} + 1.534^{*}10^{-2}\mathbf{NJ} + 8.405^{*}10^{-3}\mathbf{J2} + 6.119^{*}10^{-3}\mathbf{J1} + 3.648^{*}10^{-3}\mathbf{J5}, \quad (13)$$

$$\mathbf{THC}\ \text{(tons per morning peak hours)} = 0.05971 + 6.634^{*}10^{-6}\mathbf{PK} - 1.42^{*}10^{-2}\mathbf{HR} + 0.0164\mathbf{NJ} + 8.993^{*}10^{-3}\mathbf{J2} + 6.551^{*}10^{-3}\mathbf{J1} + 3.904^{*}10^{-3}\mathbf{J5}. \quad (14)$$

Similarly, another time limitation between 20:00 PM-23:00 PM was considered to find job trips which affect peak night air pollution. The corresponding results are shown in Equations 15-21:

$$\mathbf{CH_4}\ \text{(tons per night peak hours)} = -0.0132 + 1.276^{*}10^{-6}\mathbf{PK} + 6.993^{*}10^{-4}\mathbf{HR} + 7.704^{*}10^{-4}\mathbf{J6}, \quad (15)$$

$$\mathbf{NO_2}\ \text{(tons per night peak hours)} = -0.152 + 1.238^{*}10^{-5}\mathbf{PK} + 8.04^{*}10^{-3}\mathbf{HR} + 9.9^{*}10^{-3}\mathbf{J6} + 4.161^{*}10^{-3}\mathbf{NJ}, \quad (16)$$

$$\mathbf{CO}\ \text{(tons per night peak hours)} = -2.126 + 2.005^{*}10^{-4}\mathbf{PK} + 0.113\mathbf{HR} + 0.123\mathbf{J6}, \quad (17)$$

$$\mathbf{SO_2}\ \text{(tons per night peak hours)} = -0.016 + 8.759^{*}10^{-6}\mathbf{PK} + 8.491^{*}10^{-4}\mathbf{HR} + 1.006^{*}10^{-3}\mathbf{J6} + 6.136^{*}10^{-4}\mathbf{NJ}, \quad (18)$$

$$\mathbf{PM_{10}}\ \text{(tons per night peak hours)} = -0.0247 + 2.11^{*}10^{-6}\mathbf{PK} + 1.308^{*}10^{-3}\mathbf{HR} + 1.616^{*}10^{-3}\mathbf{J6} + 6.525^{*}10^{-4}\mathbf{NJ}, \quad (19)$$

$$\mathbf{NMVOC}\ \text{(tons per night peak hours)} = -0.178 + 1.718^{*}10^{-5}\mathbf{PK} + 9.439^{*}10^{-3}\mathbf{HR} + 0.01039\mathbf{J6}, \quad (20)$$

$$\mathbf{THC}\ \text{(tons per night peak hours)} = -0.191 + 1.846^{*}10^{-5}\mathbf{PK} + 1.014^{*}10^{-2}\mathbf{HR} + 0.01116\mathbf{J6}. \quad (21)$$

Descriptive Statistic Analysis and the Current Issues

The rates of daily passenger kilometers traveled (**PK**) in Tehran for different purposes (different jobs) in the year 2000 are shown in Figures 2-7. According to these graphs, all job trips follow similar trends in created early morning and late evening traffic peaks. They also suggest that all traffic peaks occur at the same time. However, it should be noted that white collar employees and private sector trips show a high peak, as illustrated in Figures 3-7.

Figures 8 and 9 illustrate the distribution of emissions by Tehran's transportation system.

Figure 8 indicates that, like in most cities, CO is the most prominent air pollutant in Tehran.

The graphs presented in these figures show a direct correlation between job trips and air pollution peak time. Thus, it is possible to reduce air pollution by making some modifications in the traveling time of different job trips.

According to the conducted analysis, the average commute of the private sector during morning peak hours is 8,139 kilometers, which occurs from 8 to 9 AM.

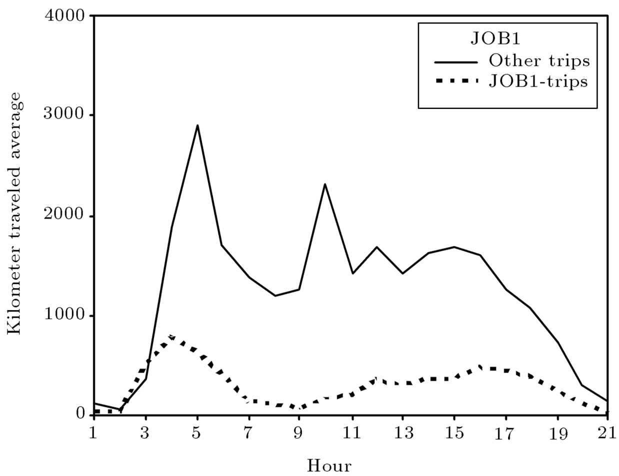

Figure 2. Tehran's daily traffic peak hours caused by labor and farmer trips; year 2000 (km/hr).

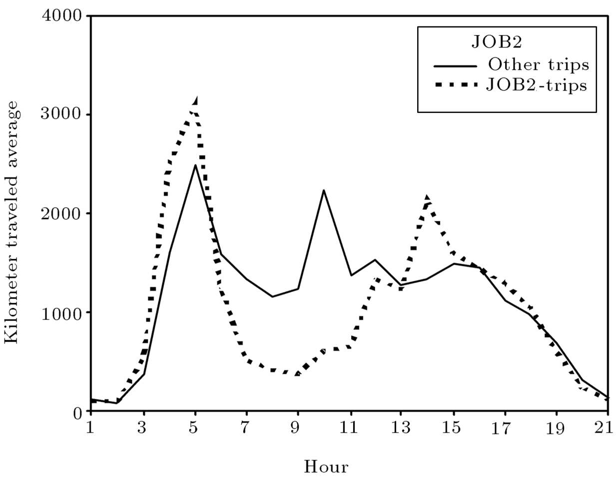

Figure 3. Tehran's daily traffic peak hours caused by white collar employee trips; year 2000 (km/hr).

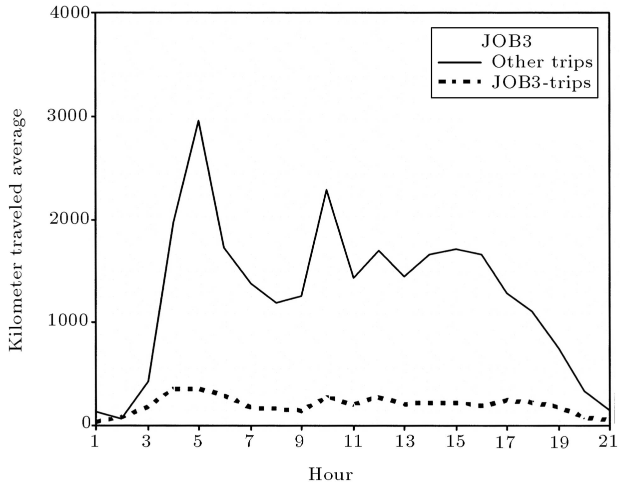

Figure 4. Tehran's daily traffic peak hours caused by driver trips; year 2000 (km/hr).

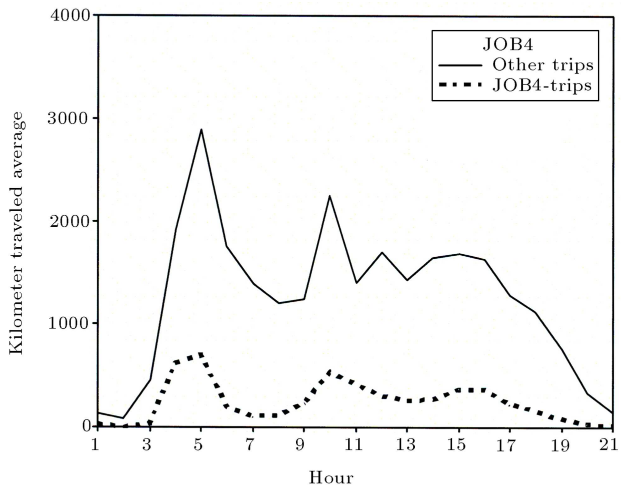

Figure 5. Tehran's daily traffic peak hours caused by teachers trips; year 2000 (km/hr).

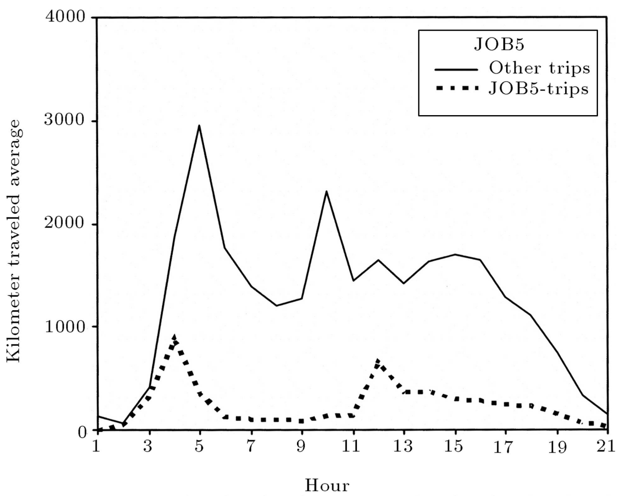

Figure 6. Tehran's daily traffic peak hours caused by army personnel trips; year 2000 (km/hr).

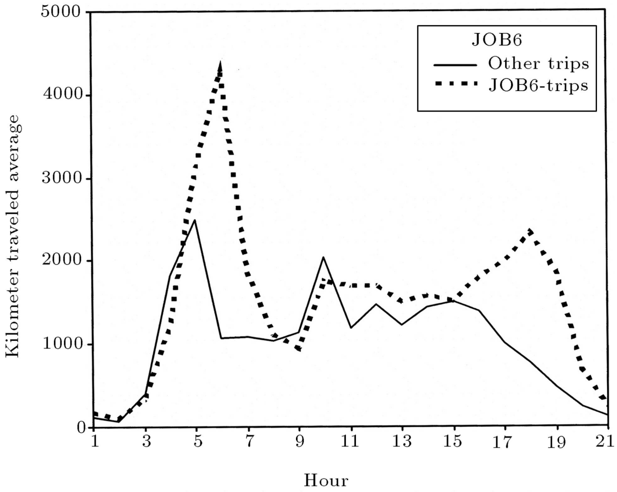

Figure 7. Tehran's daily traffic peak hours caused by private sector trips; year 2000 (km/hr).

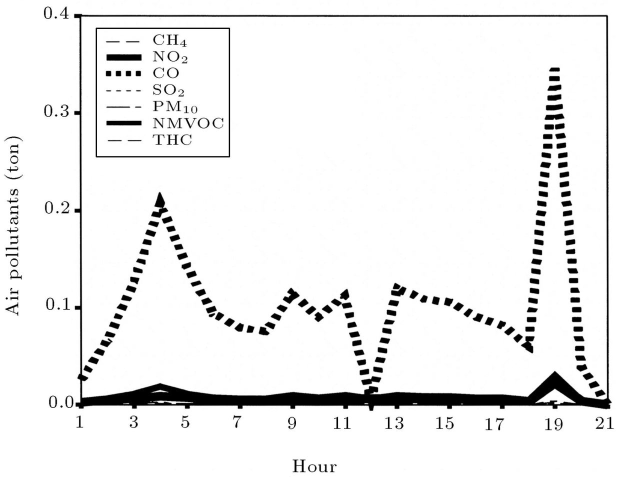

Figure 8. Air pollution caused by Tehran's daily residential vehicle trips; year 2000 (tons/hr).

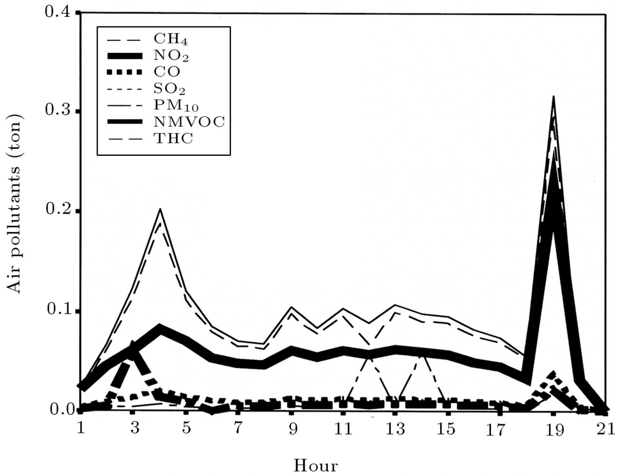

Figure 9. Air pollution caused by Tehran's daily residential vehicle trips; year 2000, excluding carbon monoxide (tons/hr).

Also, the average commute of public employees during morning peak hours is 5,955 kilometers during the 7-8 AM period. As indicated by the analysis, the morning traffic rush-hour in Tehran is between 6-8 AM, with the traffic peak at 7 AM. Thus, the morning commute of public employees offers the highest contribution to the traffic load. Also, it is interesting to point out that drivers with an average commute of 677 kilometers during the 7-8 AM time span have the least influence on morning traffic jams.

Moreover, the analysis reveals that none of the previously classified groups cause traffic at noon. However, Tehran's afternoon rush-hour is between 4-5 PM, due to the closure of public offices. The average commute of the aforesaid group is 4,071 kilometers during this period.

On the other hand, the nightly traffic rush-hour in Tehran is from 9-10 PM, mostly contributed by the commute of the private sector, with an average of 3,992 kilometers.

Also, it was revealed that the increase in the levels of air pollutants in Tehran has a linear correlation with the upsurge of traffic commutes.

Data Analysis of Influential Occupations on Air Pollution

Carbon monoxide is the dominant contributor to air pollution in Tehran, with emissions of 5,209 tons (Air Quality Control Co., 2002). Hence, based on Equation 10, the most influential occupations on the emissions of CO2 are: public employees, laborers & farmers, and army personnel. This relationship was used to study the influence of various factors on the emission of carbon monoxide. For this purpose, Time and Kilometers Traveled were assigned as the variable parameters and the parameters were used, as well as constants. So, the changes in the emissions of CO_2 during various hours and volumes of traffic commute could be assessed.

The results show that maximum emissions occur during the morning inversion from 5-6 AM (Figures 8 and 9) and morning commuters encounter high emissions of CO_2.

Equations 11 to 14 on SO_2, PM_{10}, NMVOC and THC, also indicate the meaningful contribution of public employees, laborers and farmers, and army personnel on the aforesaid pollutants, respectively. The impact of other occupations was not significant.

Equations 15 to 21 identify the private sector as being the only influential occupation having an effect on the increase of air pollution in Tehran. It is interesting to point out that the regressions conducted in this study indicate the insignificant contribution of educational occupations to this problem. Therefore, changing the working hours of schools and educational centers will not lower air pollution levels.

Due to a decrease in the self-purification capacity of Tehran's ecosystem at night and the gradual decrease of pollution with the increase in temperature, a plan for a reduction in the private sector's nightly commute is required to prevent the next morning's accumulation of air pollutants. This issue becomes prominent during the morning inversion, which poses a serious threat to the health and wellbeing of Tehran's residents.

Effect of Emission Factor and Speed on Air Pollution

Ranging from traditional transportation modeling approaches to sketch planning approaches developed in the late 1970s, as well as several more recent methodologies developed by EPA, many currently available techniques have been criticized as being too complex, too optimistic, or not sufficiently linked to appropriate emission categories to be satisfactory for use in air quality planning applications.

They generally utilize region-wide estimates of existing travel characteristics and calculate region-scale effects. If corridor, facility, or traffic analysis zone level data are available, they can be used to obtain more precise estimates, particularly with respect to speed changes [11].

Two important parameters that directly affect air pollution are the emission factor and the network fleet speed.

Figures 10 to 12 provide the distribution of the emission factor (for carbon monoxide mg/km) at the horizontal (h), downhill (d) and uphill (u) levels at different vehicle speeds (40, 60, 80 km/hr) including cars, mini-buses and buses in Tehran.

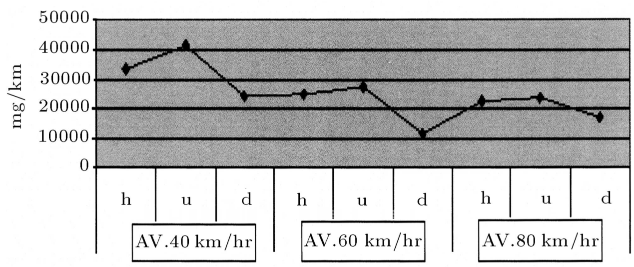

Figure 10. Carbon monoxide emission vs. speed by car.

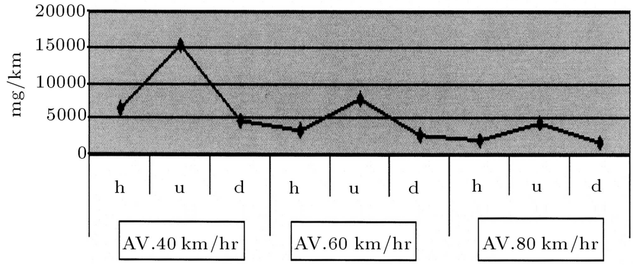

Figure 11. Carbon monoxide emission vs. speed by mini-bus.

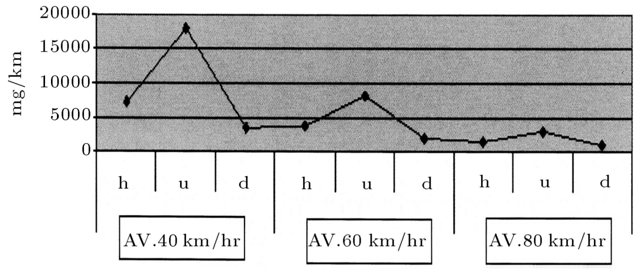

Figure 12. Carbon monoxide emission vs. speed by bus.

The coefficients of the fitted functions for the relationship between emission factors and average network speeds, are calculated as follows:

$$\mathbf{EF(cars)} = 14.8(\mathbf{V^2}) - 2086.06(\mathbf{V}) + 93040.10, \tag{22}$$

$$\mathbf{EF(mini\text{-}buses)} = 3.20(\mathbf{V^2}) - 532.89(\mathbf{V}) + 24969, \tag{23}$$

$$\mathbf{EF(buses)} = 2.53(\mathbf{V^2}) - 497.43(\mathbf{V}) + 25406.10, \tag{24}$$

where **EF** is emission factor (mg/km) and **V** is speed (km/hr).

Accordingly, the amount of carbon monoxide emissions is calculated at different ranges of speed between 20 (km/hr) to 100 (km/hr). Table 8 and Figures 13-15 comprise the carbon monoxide produced during peak hour traffic (Ton/hr) by cars, mini-buses and buses.

In regard to the emission coefficients, it is important to point out that the emission levels of air pollutants from motor vehicles were analyzed under various

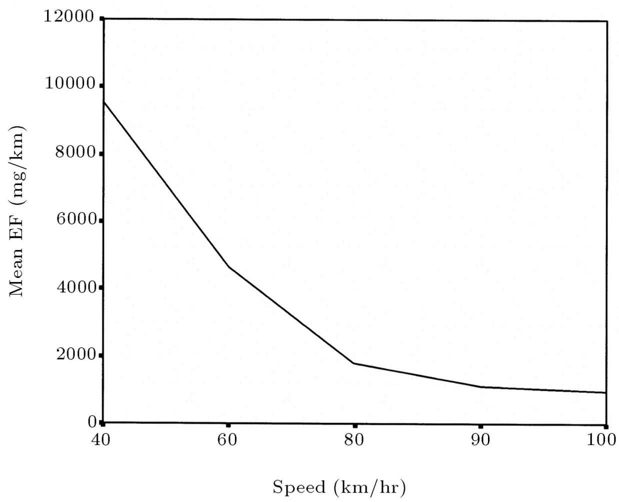

Figure 13. CO emission vs. speed by bus.

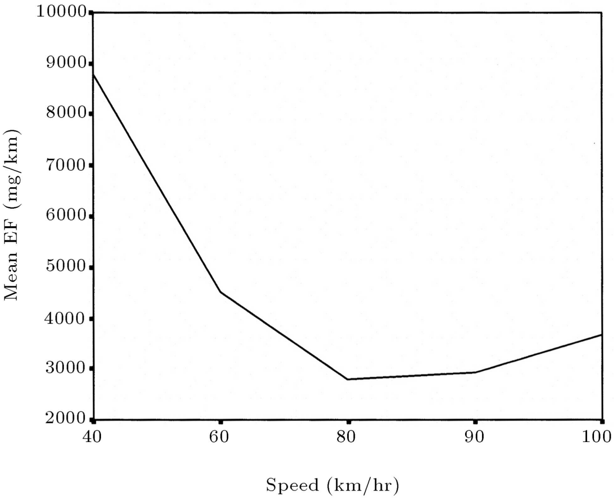

Figure 14. CO emission vs. speed by mini-bus.

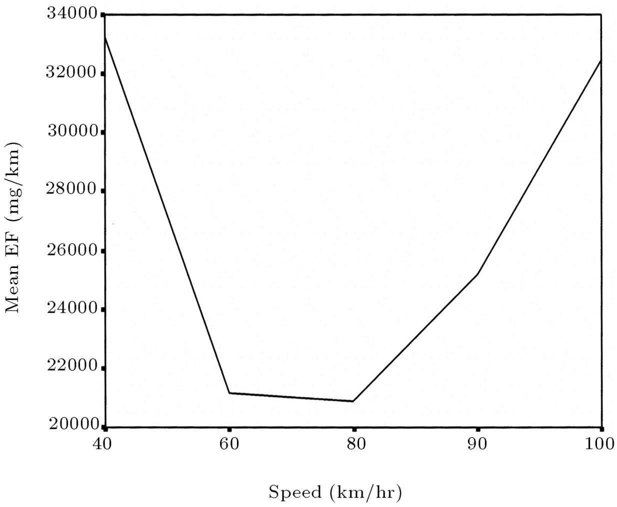

Figure 15. CO emission vs. speed by mini-bus.

speeds and conditions, like: horizontal, downhill and uphill.

Thus, based on the average speed of 29 kilometers per hour for public transportation vehicles in Tehran at the present time, the average speeds of 20 to 100 kilometers per hour were used to determine the emission coefficients for cars, buses and mini-buses. The coefficients are based on Equations 22-24.

Due to the prominence of the carbon monoxide emission volume in Tehran, it is considered as the prevalent source of air pollution.

The results of the analysis are provided in Figures 10 to 15 and Table 8, which indicates that the emission rate of carbon monoxide has a reverse correlation with the speed of the vehicle. Hence, any traffic improvement and increase in speed would reduce the amount of emitted carbon monoxide.

For example, if the speed of an average car is increased from 40 to 80 kilometers per hour, the amount of produced carbon monoxide will decrease from 472 tons per hour to 296 tons per hour for the same car. This is a reduction of about 38%, the share of which would be even greater in mini-buses (68%) and buses (81%). Therefore, development of proper provisions, such as the utilization of smart systems, would enhance the movement and the speed of public transportation vehicles and subsequently has a profound impact on the reduction of air pollutants' emissions.

Figures 13 to 15 show that the emission factor decreased at a speed of 40 to 60 (km/hrs) and Figure 15 suggests that the emission factor increased immediately in the fleet speed network over 80 (km/hrs) by car, which could result in the production of air pollution on highways.

Table 8. Carbon monoxide emission by vehicles in traffic peak hours (tons/hr).

Speed \ Vehicle	Car	Mini-bus	Bus
AV.20	813.2	84.01	225.9
AV.40	472.8	47.2	131.07
AV.60	300.6	24.3	63.9
AV.80	296.7	15.1	24.6
AV.90	357.8	15.7	15.4
AV.100	460.9	19.7	13.09

CONCLUSION

District 12 of Tehran is the most popular business destination of urban commuters. Also, the frequency of travel and related travel mileage is the highest. However, the outgoing traffic from this district to other locations in Tehran is miniscule in terms of adverse effects on traffic jams. Due to direct correlation between the amount of mileage commuted and the amount of emitted air pollutants in Tehran, it is fair to say that the high density of incoming traffic to this district has the most impact on overall air pollution in the city. The following reasons could be provided to support this theory:

- The employment level in District 12 is the highest in Tehran in 2001 with a total employee number of 349,037.
- The number of incoming commutes to District 12 was also the highest in 2001 with 430,019 travels.
- The presence of the Great Tehran Bazaar in this district, as a major commercial pole, and its location in the middle of Tehran, attracts a considerable number of incoming travelers. The number of

commercial units in this District was the highest in 2001 with a total of 81,283 shops and stores.

- There is no major expressway passing through the district.

Also, the above-mentioned analysis reveals that the number of business commutes, heavy traffic and subsequent pollution from Districts 1 to 10, have a higher impact on source areas than on sink areas in the city. This is due to the high population in each district, the number of employed people and the number of vehicles owned.

The other indicators include:

- The number of business commutes in the Greater Tehran Area consists of 39% of the total travels. From which, the share of various groups is: public employees (31.7%), teachers and students (5.8%), army personnel (5.3%), farmers and laborers (7.2%), drivers (4.7%) and private sector (45.3%), respectively.
- The most effective occupation, in terms of air pollution, is the private sector and its activities.
- Educational activities have the least impact on morning and evening traffic and subsequent air pollution.
- The 30-minute shift during working hours has no meaningful effect on the amount of air pollutants. However, the one-hour shift of working hours, as shown in Table 9, would reduce the amount of pollutants.

Moreover, the analysis indicates that the amount of emitted pollutants has a reverse correlation with an increase in the speed of vehicles and that traffic enhancement and increase of speed will reduce air pollution. Therefore, the development of proper provisions, such as the utilization of smart systems, would enhance the movement and speed of public transportation vehicles and, subsequently, have a profound impact on the reduction of air pollutant emissions.

Given undesirable air and weather conditions in Tehran, as well as the loss of human and economical resources resulting from traffic and air pollution, it is a necessity to avoid short-term solutions and, instead, look for sustainable strategies that lead to long-lasting reductions in air pollution. Taking into consideration an acceptable number of cars in Tehran compared to the number of existing cars, it is concluded that daily trips taken by Tehran residents (11,500,000), are considered the main cause of this air pollution.

Similarly, job trips in Tehran are likely to be considered the main cause of traffic and air pollution, particularly at peak time [12].

Therefore, by using traffic and air pollution forecasting models and assessing the impact of each job and trip category, it is possible to identify important jobs that cause traffic and air pollution. This model provides a minimization of air pollution, by which we can adjust the start and finish times of jobs in order to cause less traffic and, hence, less air pollution.

Having categorized jobs, the present study has identified two main job groups that cause traffic jams, i.e white collar employees and the private sector.

The present study suggests that the use of a traffic control management strategy would reduce air pollution drastically, by modification of working-times.

Some traffic control management strategies that consider a modification in working-time are as follows:

1. Compressed working hours;
2. Flexible time working hours;
3. Teleworking (providing the appropriate communication facilities).

Nevertheless, it should be noted that the application of such management measures are not responsive enough. Regarding Tehran, there must be a plan to substitute old and worn out cars with new ones in order to improve the environmental structure of the city.

According to the findings of this study and as a conclusion, some appropriate environmental management strategies are, but not limited to, the following:

Table 9. The level and percentage of reduction in various air pollutants during 24 hours in 2001 (for the peak hours and the entire 24 hours), based on the optimization practices.

Type of Pollutant	**SO_x**	**NO_x**	**CO**	**HC**	**SPM**
Reduction level at the peak hours (per ton)	0.032638	2.18826	53	3.507	0.427201
Reduction % at the peak hours	4.34%	19.65%	25.07%	20.1%	19.8%
Reduction level during 24 hours (per ton)	8.0846	110.2666	2031.3	186.0257	21.9840
Reduction % during 24 hours	0.4%	1.98%	2.61%	1.89%	1.94%

1. Programs for improved public transit;
2. Program for Automatic Meter Remote System (AMRS);
3. Employer based transportation management plans, including incentives;
4. Trip-reduction ordinances;
5. Parking facilities for multiple occupancy, vehicle programs or transit services;
6. Vehicle use restrictions in down/center town or other highly polluted areas, especially during peak use periods;
7. Programs providing for all forms of high-occupancy and shared riding services;
8. Programs limiting portions of roads or sections of metropolitan zones to non-motorized vehicles;
9. Bicycle use incentives in both private and public areas;
10. Idling restrictions;
11. Cold-start emission restrictions;
12. Employer-sponsored programs to permit flexible work schedules;
13. Programs and restrictions to promote non-single occupant automobile travel as part of the transportation planning and development efforts of a locality (new shopping centers, home shopping and teleworking) [10].

More often, several TCMs will be implemented together. However, TCMs are rarely independent of each other, thus, separate analyses of individual TCMs in a package may be misleading. Two issues should be considered when conducting an analysis of a package of TCMs: (1) Measures overlap target audiences and it is possible to double count the effectiveness of TCMs, lacking consideration of this overlap. For example, one person cannot both ride the bus and carpool to work. Similarly, some measures may be effective but may attract participants from other, preexisting programs. For instance, a rideshare participant may switch to transit if transit passes are offered; and (2) The implementation of some measures either improves or diminishes the chances for successful implementation of other TCMs. These synergies need to be recognized while analyzing the effectiveness of a given TCM (one example: Parking pricing strategies improve the success rate of other programs, such as rideshare) [13].

As a final note, it should be stressed that this approach is very new and has not been extensively tested for other urban areas or for different sets of TCM and it should also be based and recommended for future work in other cities. It is likely that the model will evolve over time as it is applied to more situations. However, the analytical framework it provides is expected to prove a useful tool for TCM evaluation.

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