J. Appl. Environ. Biol. Sci., 6(8)7-13, 2016

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

System Dynamic Modeling of Air Pollution in Megacities: An Investigation in Megacity of Tehran

Fateme Goodarzi[1*], Mahmood Ershadi[2], Mohammad Ali Arsanjani[3], Mohsen Firouzshahi[4]

[1]Department of Environmental Health Engineering, Tehran University of Medial Sciences, Tehran, Iran
[2,4]Department of Industrial Engineering, IHCU University, Tehran, Iran
[3]Department of Progress Engineering, Iran University of Science and Technology, Tehran, Iran

Received: March 28, 2016
Accepted: June 9, 2016

ABSTRACT

Industrialization and urbanization have brought along repercussions such as air pollution in urban areas. Air pollution has turned to a major concern for societies as it brings about a wide variety of problems. This reality illustrates the need for defining and formulating the air pollution problem properly. In this regard, variables have to be identified and analyzed systematically. Therefore, in this practical study, data gathering was conducted, and interviews were carried out for identifying the effective factors. Then, the interrelations among these variables were modeled, and the trend was analyzed using the VENSIM software. The investigation was carried out in the megacity of Tehran. This metropolitan has been greatly affected by air pollution due to its special geographical situation. Finally, dynamic relationship between variables and their contribution to the whole system was simulated. The result of the simulation shows that the "public transport" as the leverage variable has the most influence on air pollution among other effective variables.
KEYWORDS: Air pollution, System Dynamics, Megacities, Modeling.

1. INTRODUCTION

Air pollution is considered as the introduction of particulates, or other harmful gases into Earth's atmosphere, causing disease to humans, and damages to other living organisms and the environment. Air pollution has been the main problem in megacities in recent years. Megacities are considered as the largest and most developed cities in countries. Urban air pollution, however, is a serious problem in these cities. The traffic and exhaust gas emissions are considered as major causes of air pollution in megacities [1].Traffic emissions are considered as damaging substances for the ozone reaction. The worst pollutants which badly affect the urban areas include Sulphur Dioxide, suspended particulate matter, Carbon Monoxide, Nitrogen Dioxide, Lead, and Ozone [2]. Identifying air pollution variables is important in the policymaking process.

A number of prior researches have been conducted to simulate the air pollution problem and provide a systemic outlook for practitioners. Schmidt offered an integrated simulation system for simulating the air pollution in relation to traffic [3]. Kessler also developed a more detailed simulation model of air pollution based on nested models in North Rhine-Westphalia [4]. Cai and Xie applied a model for evaluating the impact of a traffic restriction scheme on traffic-related air pollution in Beijing before, during and after the 2008 Olympic Games [5].Furthermore, Misra adopted an integrated modeling approach for estimating urban traffic emissions. The modeling framework consists of a traffic micro-simulation model developed in a microscopic emissions model and two dispersion models. This framework was applied to a traffic network in Toronto to evaluate summer time morning peak traffic emissions of carbon monoxide and nitrogen oxides [6]. In 2014, many researches were conducted to model air pollution more exactly. Hulsman linked traffic models with air pollution models for analyzing the impact of transport policies on the environment and human health. In this study, an approach is developed that links the multi-agent-based transport model with the calculation of air pollution based on the Operational Street Pollution Model. Traffic-related air pollution is modelled while still being applicable to large-scale scenarios. Nitrogen dioxide emissions and concentrations are simulated for an area bounded by the major ring road of Munich, Germany [7]. As further studies, Kumar developed an Artificial Neural Network model to predict highway traffic noise. The input parameters of this model are total vehicle volume/hour, percentage of heavy vehicles and average vehicle speed [8]. Manley introduced a hybrid agent-based modeling framework for balancing the demands of behavioral realism and computational capacity. This framework integrates a descriptive representation of driver behavior with a collective model for traffic flow. The hybridization of these approaches within an agent-based modeling framework resulted in representing the urban traffic flow that is driven by individual behavior, yet, in reducing the computational intensity of simulated physical interaction, enables the scalable expansion to large numbers of agents [9]. Domanska developed a model for predicting emission concentrations of PM10, SO2, O3. This model is an extension of the Air Pollution Forecasting Model (APFM) which requires historical data for a large number of points in time, especially weather forecast, meteorological and pollution data. E-APFM needs information about the wind direction in sectors as well as meteorological station [10].

*Corresponding Author: Fateme Goodarzi, Department of Environmental Health Engineering, Tehran University of Medial Sciences, Tehran, Iran. E-mail:f-gudarzi@alumnus.tums.ac.ir

Other aspects of air pollution, especially the health concerns, were explored in recent years. Khaki and colleagues studies the noise pollution and its harmful effects on public health in Tehran metropolitan. In this case study, the noise levels generated in the area in a 7.5-meter distance from the highway was calculated and a linear model was developed. They validated their model through examining data. The correlation of the linear model was equal to 0.871[11]. In another research, EL-Bady assessed the heavy metal pollution level in dust generated on the expressway. In this paper, pollution levels were estimated based on Pollution Load Index, Contamination Factor, Degree of Contamination, Geo-accumulation index and potential ecological risk index. This researcher concluded that the pollution level increases due to the increase of the populations, vehicles and industrial activities around the Benha-Cairo expressway[12]. Also, Munir and colleagues examined the health Effects due to air Pollution in Children and Adults in Urban Area. The authors estimated the trace metals in particulate matter and studied the health effect of air pollutants. As the result four metals were identified in Particulate Matter which includes cadmium, chromium, lead and nickel[13]. The findings of these studies reveal that air pollution greatly affects human health, and therefore more in-depth research on effective factors in air pollution needs to be conducted.

Regarding the above-mentioned studies, up to now many researchers have tried to simulate and analyze the air pollution problem accurately. However, none of them have applied system dynamics method. System dynamics is considered as an effective approach for management problems, and can be applied properly to simulate problems based on identifying the variables and their relations in defined context [14,15]. Therefore, in current study system dynamic is applied as an effective tool to simulate the air pollution problem.

2. MATERIALSAND METHODS

This case study research is carried out in Tehran megacity, and the projection data is limited to the time period between 2014 and 2024. Research method is based on interview with experts selected based on purposive sampling method. Furthermore a questionnaire was used. The Statistical population include the academic experts in the field of air pollution.

The steps of this research include:

1. Carrying out literature review and gathering data from valid sources to identify variables.
2. Examining variables and obtaining viewpoints of air pollution experts using a questionnaire.
3. Modeling the air pollution problem based on real data gathered from air quality control organization and other valid sources.
4. Testing the validity of the model through interviewing with academic experts.
5. Running the system dynamic model in VENSIM software to predict the effects of policies.

Regarding the results of the interviews, assumptions of the model is that the time period for simulation is from 2014 to 2024. Furthermore, the variable of PM 2.5will be considered as an output variable which shows the amount of the air pollution(as environmental authorities of Iran have asserted that the main reason for air pollution in Tehran is PM 2.5). It should also be mentioned that the initial amount of variables were extracted from Tehran Air pollution report in 2014. Finally, the validation of the system dynamic simulation model was checked through interviewing with experts.

3. RESULTS

3.1. Variables

Identifying the variables: First and foremost, the variables affecting the air pollution should be identified. Therefore, a comprehensive survey was conducted to gather and analyze data. Sources include literature, responsible organizations for air pollution and experts. As the results, the key variables include the average amount of PM 2.5(air pollution variable) (In microgram per cubic meter), fuel consumption (In litre), private car commuting(The number of private cars commuting in the city)the amount of traffic (The volume of traffic), the scope of traffic district(The number of urban regions within the business district), the scope of odd and even district (The number of urban regions within the odd and even district), fuel consumption proportioning (the share of fuel for each car), public transport (The number of public vehicles), outdated motor vehicles (The number of outdated motor vehicles), dual-fuel vehicles (The number of vehicles consuming two fuel), industrial pollution (In gram), the technical inspection (The number of vehicles checking out), urban trees and vegetation (The amount of decreased vegetation duo to air pollution), and other effective variables which are mentioned in the conceptual model.

Assigning the value: In order to assign values for the variables, the reports of Tehran air quality control, environmental research institutes and relevant organizations in 2014 were considered. For instance, on average, the amount of PM 2.5 in this year was 32 microgram per cubic meter. The number of daily private motor vehicles commuting in the city was approximately7 million, and the amount of fuel consumption was approximately 13 million litre.

3.2. Modelling

At the first step of the modeling, the cause and effect loops have to be determined by assessing the relations between variables. These loops were depicted in VENSIM software based on the real data (The loops are illustrated in following figures). These loops, which are shown in figure 1, indicate the interactions between effective variables.

Private car commuting leads to higher fuel consumption and higher amount of the traffic. Both of these variables increase the air pollution.

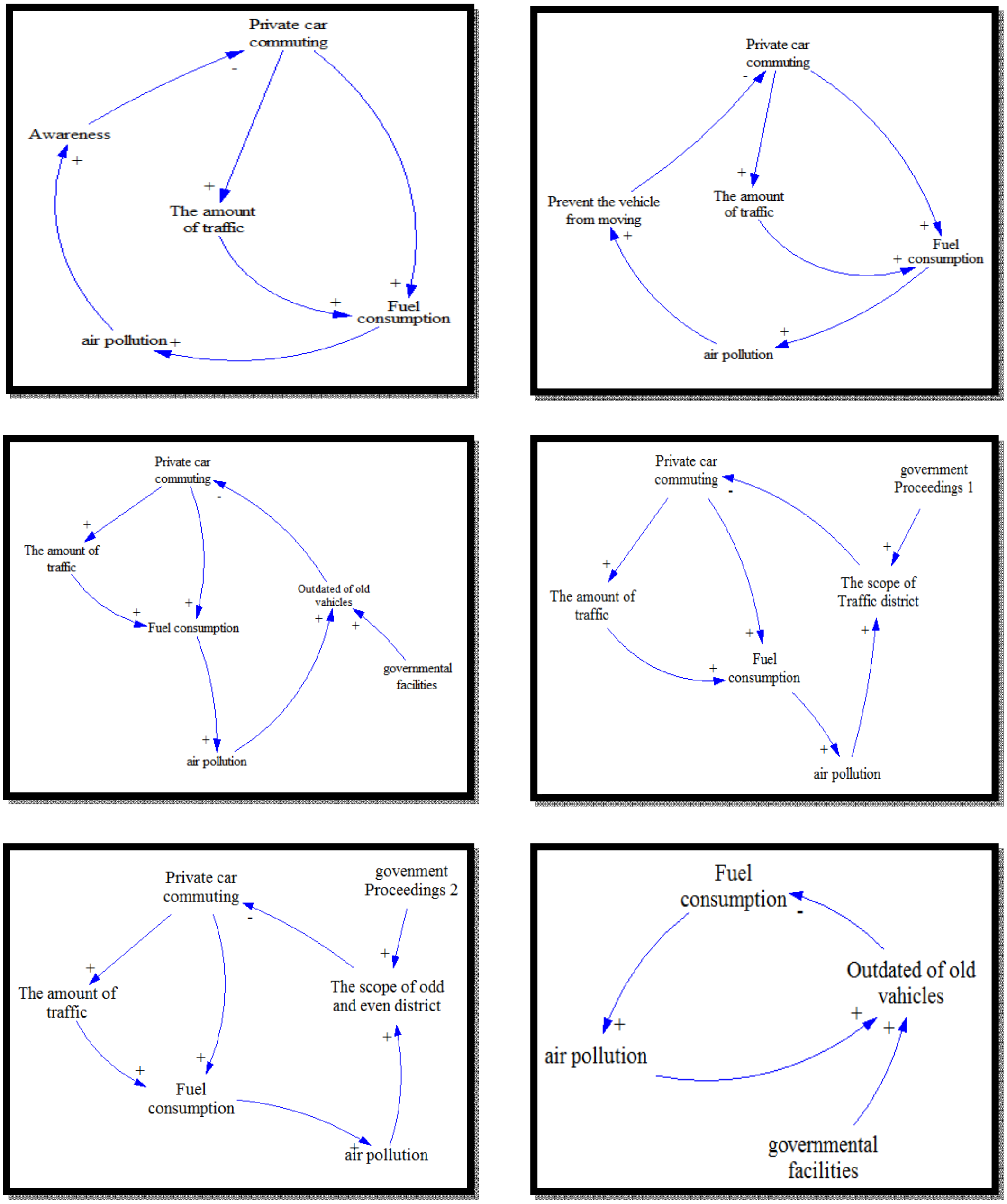

Figure 1.cause & effect loops

According to the cause and effect loops (figure 1), the system dynamic problem can be modeled. In this regard, the communalities between cause and effect were taken into account and consequently the loops were integrated in a comprehensive model showing Tehran air pollution problem (figure 2). In fact, the close loops which are shown in figure 1 where consolidate in a wider frame. It is obvious from the diagram that public transport, private car commuting, fuel consumption, and outdated car vehicles are considered as important variables in the air pollution problem.

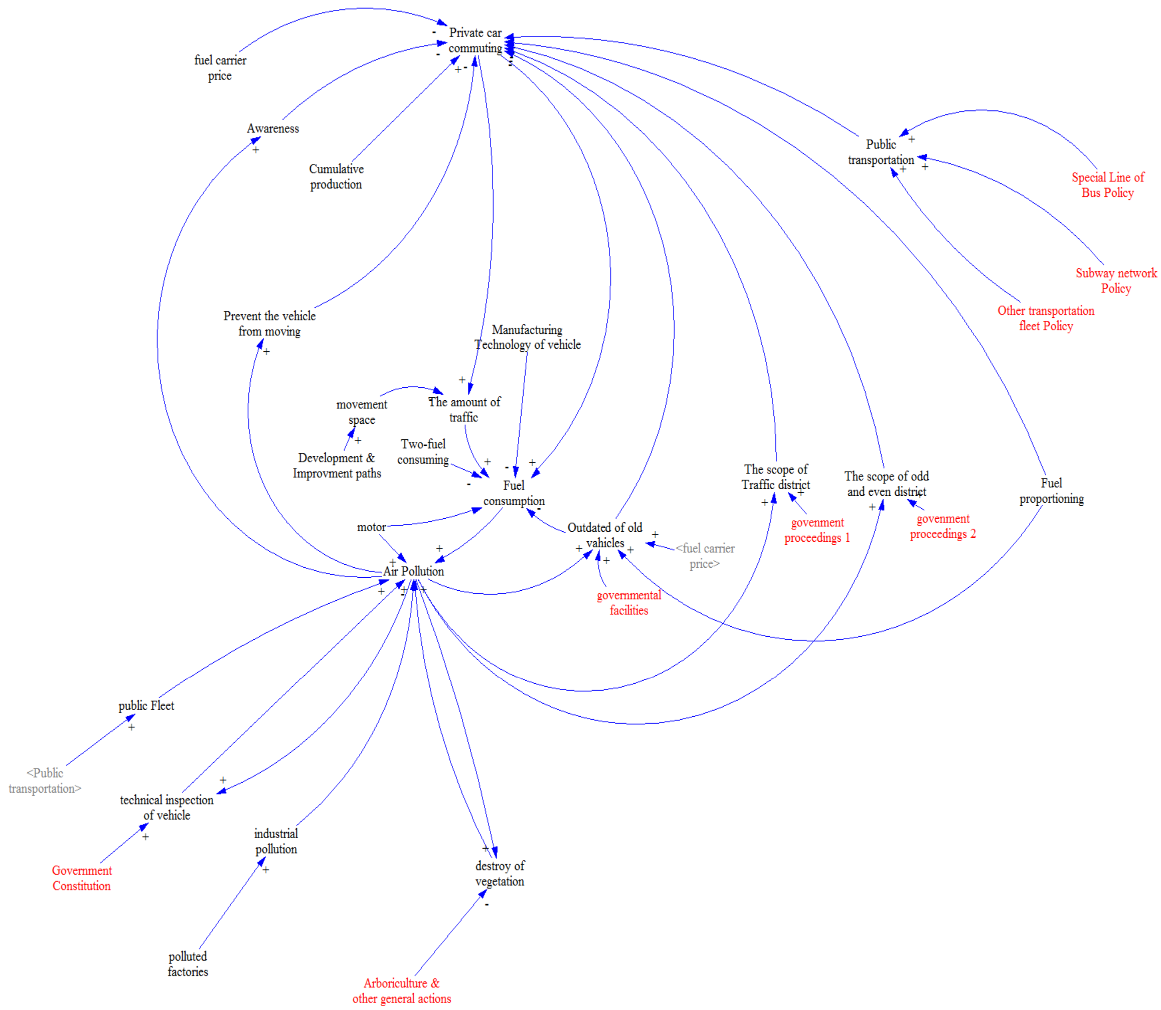

Figure 2. The comprehensive model of cause & effect loops

In the next step, the stream model was depicted that illustrates the main interactions between variables and the overall effects. The quantitative relations were calculated based on data collected from organizations and valid sources. Then, the relations were formulated in VENSIM (figure 3).One of the basics of the model is to identify the stocks and flows in the air pollution problem. In this regard, it should be determined which variables in the system experiencing the problem define its state (stocks), and which variables define the changes in its state (flows). Entities can move through flows (inflow and outflow) and accumulate in stocks. If the inflow exceeds the outflow the number of entities in the stock will increase[16]. The stocks and flows are shown in figure 3. It should be mentioned that the quantitative model was approved by experts.

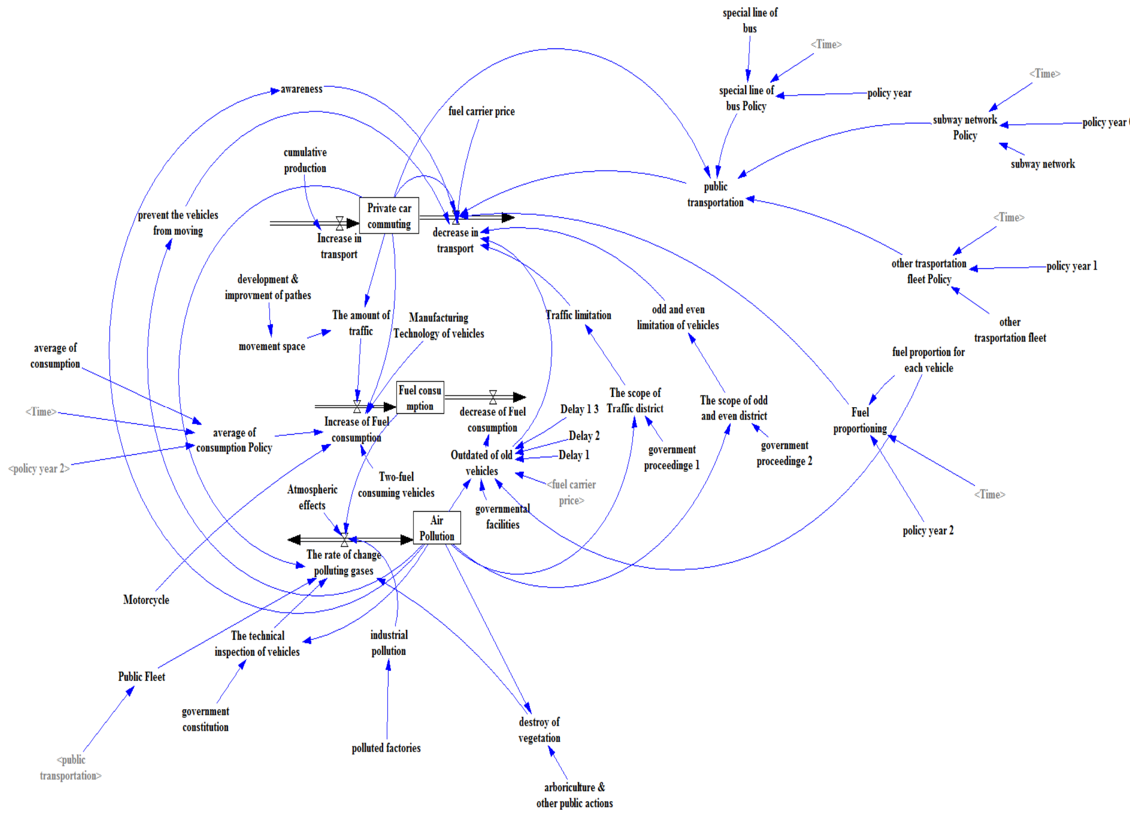

Figure 3. System dynamic model of air pollution problem

3.3. Scenarios

Results of the sensitivity analysis in VENSIM illustrate that the "public transport" as the leverage variable plays an important role in controlling the air pollution. Furthermore, although there are many ways to control air pollution, the major focus of many countries have been on developing the public transport fleet to solve this problem. Therefore, in this article the effect of the policy "developing the public transport fleet “on the air pollution were analyzed based on the quantitative system dynamic model. The future trend of the system was analyzed for two scenarios, with and without considering the policy using the VENSIM software.

The scenario 1(without considering the effect of the policy): The amount of the air pollution, without considering the effect of the policy, is illustrated in figure 4.The curve indicates the average amount of air pollution in the form of PM 2.5in urban areas of Tehran in microgram per cubic meter from 2014 to 2024.It is obvious from the diagram that the trend is upward and the average amount of pm 2.5 in urban areas of Tehran will reach 79micro gramper cubic meter until2024 (figure 4).

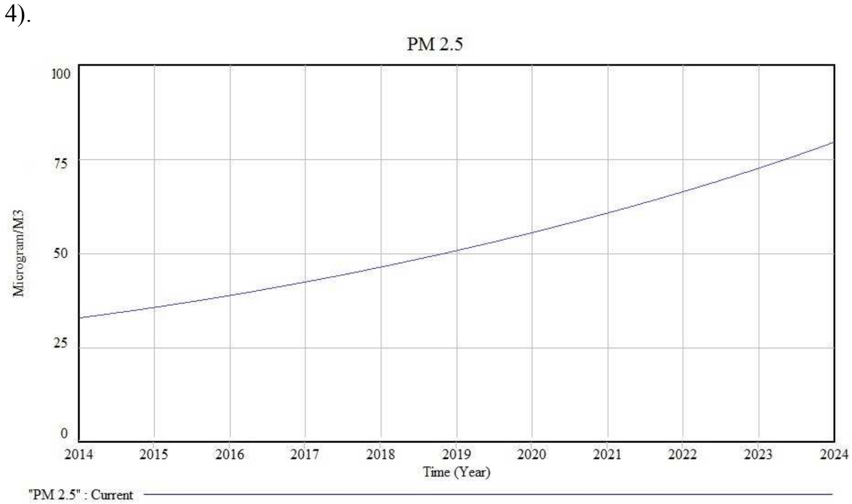

Figure 4. The air pollution trend without considering the effects of policies

The scenario 2 (considering the effect of the policy): The amount of the air pollution in the form of pm 2.5, considering the effect of the policy, is illustrated in figure 5. The diagram shows that the average amount of pm 2.5in Tehran will reach 48microgram per cubic meter until 2024. This scenario shows that there will be a slight decrease in the slope of the curve after 2020 in comparison with scenario 1 (figure 5).

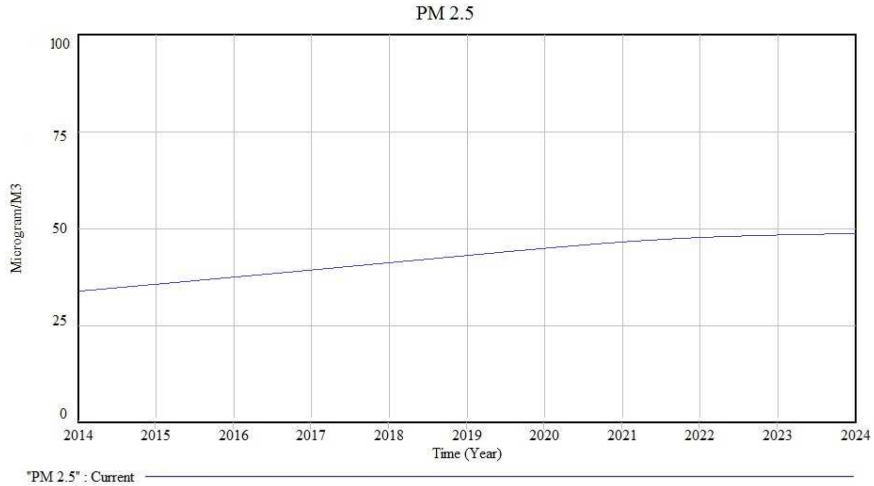

Figure 5. The air pollution trend considering the effects of policies

4. DISCUSSION AND CONCLUSIONS

The results of the literature review showed that air pollution greatly affects human health, and therefore more in-depth research on effective factors in air pollutions need to be conducted. Furthermore, none of the previous researched offered an exact quantitative system dynamic model for simulating the air pollution problem in urban areas. System dynamics approach is capable of structuring relations, and creating a suitable model to simulate the whole system. This approach provides the environmental decision makers with sufficient background about the consequences of their decisions. Regarding the importance of air pollution in megacities, system dynamic was applied in this study to provide a basis for analyzing the variables and modeling the interrelationships.

In this article, key variables of air pollution were identified as the result of a survey. The key variables include: The amount of pm 2.5, Fuel consumption, private car commuting, the amount of urban traffic, the scope of traffic district, the scope of odd and even district, fuel proportioning, public transport, outdated motor vehicles, dual-fuel motor vehicles, industrial pollution, the technical inspection, and the urban vegetation. After identifying the variables, the system dynamics method was applied to model the interrelations of variables and their effects. Then, the effect of policy on the system was examined using VENSIM software. The public transport was identified as the leverage variables influencing the whole system. In this regard, the effect of the policy, developing the public transport fleet, on air pollution was analyzed. Two scenario were analyzed to compare the effect of the policy. The future trend was analyzed for two scenario, with and without considering the policy using the VENSIM software. The results of this analysis show that there will be a slight decrease in the slope of the curve after 2020.

In comparison with similar researches, this study provides a more exact basis for simulating the air pollution problem. Previous researches have not focused on the dynamic interrelations among variables of air pollution. Whereas, considering the dynamic environment is of crucial importance in the air pollution problem. Therefore, the major focus of this study is on dynamic relations. In this regard, the relation between variables were formulated and inserted in the VENSIM software. Another point is that other researches have not focused on assessing the effect of policies on air pollution in the long term. However, in the current research a projection to 2024 was presented and two scenarios were compared.

As a whole, the below suggestions have been mentioned by experts based on the analysis of model to decrease the air pollution in megacities like Tehran: Excluding old cars, improving the vehicle fuel system, improving the quality of fuel, public transport development, locating the factories in suburbs, landscaping, and developing electronic services.

5. REFERENCES

1. Babran. S. andA. Ghamkhar, 2007.The consequences of air pollution, J Environ Sci, 24, 24-31.
2. Safavi. Y, and B. Alijani,2006. Evaluating the effect of geographical factors in Tehran air pollution, Geographical Res, 58, 99-112.
3. Schmidt. M, and R. Schafer, 1998.An integrated simulation system for traffic induced air pollution, Environ Modell Softw, 13, 295-303.

4. Kessler. C, and M. Brucher, M. Memmesheimer andA,Kerschgens,2001. Simulation of air pollution with nested models in North Rhine-Westphalia, Atmos Environ, 35, 3-12.
5. Cai. H, and S. Xie,2011. Traffic-related air pollution modeling during the 2008 Beijing Olympic Games: The effects of an odd-even day traffic restriction scheme, Sci Total Environ, 409, 35-48.
6. Misra. A., M. J Roorda, and H. L. MacLean,2013.An integrated modeling approach to estimate urban traffic emissions, Atmos Environ, 73, 81-91.
7. Hulsmann. F., and R. Gerike, and M. Ketzel, 2014. Modeling traffic and air pollution in an integrated approach: the case of Munich, Urban Climate, 10, 732–744.
8. Kumar. P., S. Nigam, and N. Kumar,2014.Vehicular traffic noise modeling using artificial neural network approach, Transport Res, 40, 111-122.
9. Manley. E., T. Cheng., A. Penn, and A. Emmonds,2014.A framework for simulating large-scale complex urban traffic dynamics through hybrid agent-based modeling Computers, Environ & Urban Systems, 44, 27-36.
10. Domanska. D, and M. Wojtylak,2014.Explorative forecasting of air pollution, Atmos Environ.
11. Khaki. A. M, A. E. Forouhid, and H. Chegini. 2015. Traffic Parameters and Noise Pollution of Highway, J. Appl. Environ. Biol. Sci. 5(5): 124-128.
12. EL-Bady. M. S. 2014. Road Dust Pollution by Heavy Metals along the Sides of Expressway between Benha and Cairo, Southern of Nile Delta, Egypt, J. Appl. Environ. Biol. Sci. 4(12): 177-191.
13. Munir. A, A. B. Tabinda, and A. Ilyas. 2014. Health Effects Due to air Pollution in Children and Adults in Urban Area, J. Appl. Environ. Biol. Sci. 4(5): 55-59.
14. Teymori. A., A. Norali, and N. Valizade, 2013. System Dynamics: A practical approach for management problems, 1st edn, Iran university of Science and Technology, Tehran, pp. 89-91.
15. Boulding. K.E, 2004.Contract General Systems Theory: the skeleton of science, Manage Sci, 6, 127-139.
16. Forrester, J.W. 1975. Collected papers of J.W. Forrester, Pegasus Communications, USA.
17. Tehran air quality control company, 2014, Tehran annual air quality report, Shahr publication, Tehran.