Transportation Research Part D 31 (2014) 21–36

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

A system dynamics modeling for urban air pollution: A case study of Tehran, Iran

Hamed Vafa-Arani, Salman Jahani, Hossein Dashti, Jafar Heydari *, Saeed Moazen

School of Industrial Engineering, College of Engineering, University of Tehran, Iran

ARTICLE INFO

Keywords:
Urban air pollution
System dynamics modeling
Traffic
Public transportation
Energy fuel and automotive industries

ABSTRACT

Development of strategies to control urban air pollution is a complex process involving a wide range of sciences. In this study a system dynamics model is proposed in order to estimate the behavior of parameters affecting air pollution in Tehran. The proposed model includes two subsystems: (1) urban transportation, (2) air polluting industries. In this paper, several policies are proposed to mitigate air pollution. The proposed model is simulated under several scenarios using historical data of transportation and industrial sectors in Tehran. Policies are categorized as: (1) road construction, (2) technology improvement in fuel and automotive industries, (3) traffic control plans, (4) development of public transportation infrastructures. The results show effectiveness of the proposed policies. In this case, technology improvement in fuel and automotive industries and development of public transportation infrastructures are more effective policies in order to reduce air pollution.

Introduction

Rapid urbanization may cause different environmental pollutions, such as air pollution, acid rain, water pollution and land pollution, solid wastes, toxic wastes and deforestation. In the metropolitans of developing countries especially in Asia, the environmental problems are much greater, because of the overwhelming scale and speed of urbanization (Atash, 2007). Air pollution has become an undeniable problem of most countries. Reducing urban air pollution has been on the agenda of policy makers for several decades, especially in United States and Europe. A long list of consecutive initiatives, often of an international nature, has been taken to reduce emissions of key pollutants (Beckx et al., 2009). But this trend is reverse in developing countries, especially in Asian countries. Remarkable negative effects of air pollution on public health, environment and economic, can oblige the decision makers to plan for controlling and eliminating the main sources of pollution in these countries. Since the air pollution can affect several facets of urban human life, it can be affected from several man-made systems including public and individual systems, industrial plants and household which are the main sources of urban air pollution. Transportation, industries and houses cannot be considered as some independent systems in urban areas. These systems have several interactions with each other while all of them are affected by human behavior, so air pollution is a socio-economic problem in which both facets of it should be analyzed. Thus, all of these systems should be considered as subsystems of a greater one, which includes all the systems within a city as well as other exogenous systems influencing the urban system. In addition to interactions between different subsystems, feedback structure should be taken into account which implies dynamic loops. System dynamics modeling is one of the best tools to model a socio-economic

* Corresponding author. Tel.: +98 21 82084489.
E-mail address: J.heydari@ut.ac.ir (J. Heydari).

http://dx.doi.org/10.1016/j.trd.2014.05.016
1361-9209/

problem with mentioned characteristics. System dynamics can model feedback structure as well as interactions between several variables in a system by means of simulation which can demonstrate the future effects of policies in different variables and subsystems. Socio-economic systems- like the one considered in this study-are complex and their behavior cannot be estimated through analytical methods. In such systems, a simulation approach could be utilized to explore behavior of the system. Among several simulation methods, systems dynamics approach is an appropriate and effective one for socio-economic systems.

Tehran Province has a population of around 12.4 million and surpassing 8.3 million in the wider metropolitan area according to 2012 census (Statistical Centre of Iran, 2012). Ineffective public transportation infrastructures, non-standard streets and highways, population congestion, non-efficient urban management and planning, and several other reasons cause high traffic congestion in the metropolitan area of Tehran.

Inversion can lead to pollution such as smog being trapped close to the ground. In recent years, inversion has caused several closures of schools and government centers during winters in Tehran which lead to serious economic losses, environmental damages and mortality increase. Accordingly, in this paper urban transportation subsystem is considered as the main subsystem which can affect other subsystems and be affected by them. Two major types of trips in urban areas are public and individual trips. The portion of trips by personal automobiles can show the situation of transportation system of the city. High level of public trips shows the strength of public transportation infrastructure and public transportation attractiveness for people. On the other hand, high level of individual trips in a specific city shows high driving attractiveness which originates from several factors such as low travel time by individual automobiles with respect to public transport, expensive public transportation fare, cheap automobiles and cheap fuel for automobiles. In order to reduce the traffic congestion which is the most important source of air pollution, several policies can be made. Road construction, traffic congestion control plans, and investment on public transportation system are practical ones in Tehran. The effects of mentioned policies on the urban air pollution are investigated in the proposed system dynamics model.

Majority of industrial countries are faced with pollutant industries more than the past. Especially, in developing countries such as China, industrial air pollution is not only a source of urban air pollution, but also is a global problem which causes global warming and Ozone layer destruction. In the current study, boundary of the model does not include this later issue, thus it is considered that urban air pollution is caused by suburban factories. Two major groups of polluting industries around Tehran are automotive and fuel production industries. In addition, these two industries are the most related to the urban transportation systems. Therefore, industrial pollution resulted from automotive and fuel production industries form the first part of industrial subsystem.

Energy is one of the most important resources of the mentioned industries. Fuel and automotive production industries are two of the most energy consumers in Iran. Meanwhile, required energy for these industries is generated by power plants around them. In other words, power plants around Tehran should generate required energy for the industries. In urban areas, household consumers are the major consumers of energy. Thus, two major consumers of energy are industries and households. As the power plants cause major pollution, they are considered as the second part of industrial subsystem.

In this paper a system dynamics model is proposed to cope with complexities of urban air pollution problem which includes two major subsystems: (1) transportation subsystem, and (2) industrial subsystem. Subsystems and variables are consistent with case of Tehran. It is first time which a system dynamics model is developed to investigate the air pollution problem of Tehran from urban management perspective by considering interactions of two aforementioned subsystems. Remarkable contributions of the model could be classified to two major groups. First, although, usually traffic congestion is considered as the main factor of urban air pollution, pollutant industries should be taken into account as another source of urban air pollution, especially in industrial cities such as Tehran. In this study, industrial pollution is considered as one of the main causes of urban air pollution. In addition, fuel and automotive industries as the most effective industries on the air pollution associated with automobiles. Automobile and fuel quality are variables which are related to industrial and transportation subsystems. Second contribution of this paper is about several novel applicable policies for mitigating the air pollution. Road construction, technology development in fuel and automotive industries, applying traffic control plans and developing public transportation infrastructures are four proposed policies which are investigated.

Literature review

Urban air pollution has become one the most critical problems in several metropolitans over the world. Previous studies investigated the urban air pollution problem with several perspectives using different approaches and tools. The current study is not based on technical and chemical aspects of the urban air pollution. But, strategic decision making in urban air pollution problem is investigate. All of studies in the field of urban air pollution could be categorized into two major groups. First, studies that investigate the air pollution through analytical modeling methods such as operations research. Second group includes studies which utilize system dynamics approach to model the air pollution and not necessarily urban air pollution. The body of literature in air pollution modeling is reviewed here according to aforementioned classification.

In the first class, Sivacoumar et al. (2001) utilized a mathematical programming approach to predict the air pollution of Jamshedpur region of India. They indicated the portion of domestic, industrial and automobiles from NO_x pollution which the results show that the contribution of each part was 53%, 7% and 40%, respectively. Ulke et al. (2001) investigated the