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INVESTIGATING THE PROBLEM OF POLLUTION IN CITIES AND PROVIDING THE SOLUTIONS USING SYSTEM DYNAMICS METHOD

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Abstract: The greatest environmental problem of cities is air pollution that natural and human factors are involved in creating it. Natural factors influencing it include city surrounding by mountains, lack of constant winds with proper speed, and low rainfall. Among the human factors, we can refer to existence of large numbers of vehicles and cars, introduction of excessive new cars to urban traffic cycle, insufficient or reluctance to use public transport systems and the cheap price of fuel. The concentration of atmospheric pollutants in the cities in many cases is several times more than the allowed level, followed by short and long term adverse effects. The first step to control air pollution of the cities is the identification of effective resources and sharing the relative pollution production rate. Sources of pollution include stationary sources (units with different land uses including residential units, factories, and industrial workshops, and refinery) and mobile sources (including public and private light and heavy vehicles). Methods to determine the relative contribution of the sources include the use of emission factors and calculating emissions at the source of pollution production that the focus of this method is on emission source. Another approach is to focus on the current situation by measuring the concentration in pollution monitoring stations or reverse modeling to detect emission source. In this research, the transport system of cities and its impact on air pollution, the economy, and the population are studied. Effective variables and parameters were identified and causal loops were designed and the equations and model were calibrated and validated using information and Vensim software that showed very good accuracy. Using this model, the effect of different scenarios to reduce air pollution caused by transport was investigated.

Keywords: pollution of cities, system dynamics method, air pollution reduction, traffic reduction

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1. INTRODUCTION

Despite statistics on the comparison of the pollutants level of cities with global standards, it is not surprising to state that the main environmental problem of the cities is the problem of air pollution. Millions of people breathe highly polluted air daily and in the case of continuing growth of pollution production resources, this problem will be a human disaster. The result of fuel consumption in various sectors is production of particles and gases that continuous exposure to them is followed by hazardous problems and complications for human health and other living organisms and this is only one part of adverse effects of air pollution. Nowadays, there is less artificial good that oil products have not been used in its production. Technology provides every day more useful uses of this black gold and it is at least used in burning them. However, major part of cities pollution caused by incomplete fueling of the oil products in various applications. It is interesting that in cities about nine million liters of gas is used daily in the transport sector. The vital question is that which factor is involved in this situation. If we want to solve the problem of air pollution in the cities with expert decisions and right decisions, it will certainly impossible overnight and without the use of a correct and clear reports of the factors involved in such positions. Therefore, models, created on the basis of causal loops by studying the problem of the pollution in cities, are simulated by identifying the factors affecting the system behavior and adopting various controlling policies. In order to simulate this system behavior, subsystems are identified firstly. Then, by determining the boundaries of the system, original influential variables are determined, and math equations are extracted on the basis of historical data. Within the framework of a complex causal relationship of this system, the effect of different policies on the reduction of air pollution of cities can be measured. The data needed to develop and simulate such a system, a variety of similar resources such as environmental data, traffic data, and so on have been extracted.

2. REVIEW OF LITERATURE

In this section, research studied the problem of air pollution by different methods are reviewed. Firstly, studies examined this problems by using other techniques are reviewed (except the dynamics of the system). Then, with approach of systems dynamics, this issue is investigated. Schmidt and Schafer (2014) provided a computing network with high-performance to study air pollution using traffic simulation. Their work focuses on the effects of pollution caused by transport on total air pollution in European cities (Schmidt & Schäfer, 2014). Sivakimar et al (2013) predicted the air pollution of Jamshedpuvr city using mathematical modeling approach. Their studies showed that 53 percent of pollutions and 7% related to internal resources and 40% related to NOx related to the transport (Sivacoumar et al., 2013). Box et al (2012) provided a model to assess the impact of demographic changes on pollution air and showed that the population travel to urban areas daily has a significant impact on levels of air pollution (Beckx et al., 2012). Vlakastas et al (2014) used a mathematical modeling approach to calculate the optimal parameters in the long policies to reduce air pollution in the city of Thessaloniki in Greece (Vlachokostas et al., 2014). Anne (2013) modeled the city transportation issue in Taiwan where motorcycle is the main means of transport by using systems dynamics modeling. In this research, policies of development of public transport system, the development of the capacity of the roads, and travel demand control in order to reduce urban traffic were studied (Tseng et al., 2013). Zarka et al (2014) examined systems dynamics approach to the management of environmental pollution and studies showed that pollution caused by agriculture, industry, home, service, transportation, and the input streams from other areas are considered factors that aggravate pollution and output flow to other areas are considered in the modeling (Szarka, N., et al., 2014).

Wang et al (2012) studied the transport system in Dalian city in China using systems dynamics approach.

The proposed model included seven smaller factors including population, economic development, and number of vehicles, environmental impact, travel demand, transport supply, and traffic volume (Jifeng et al., 2012). They examined the air pollution of metropolitans taking into account the health effects of population growth. They showed firstly feedback effects of various factors with loops of cause and effect. Then, using case and flow diagram, they simulated the system. Effective variables in their model included urban population, patient urban population and air pollution caused by industrial and domestic use (.Shahgholian & Hajihosseini, 2013). Arme et al. (2010) examined the air pollution caused by air transport system of the city of Accra in Ghana using dynamics of systems approach where traffic volume was considered as factor involved in increased air pollution. They considered factors such as the development of public transport, the development of the capacity of the highway and travel demand management in their models as policies to reduce air pollution (Armah et al., 2010).

Liu et al. (2009) provided a Congestion Pricing Model for solving the problem of traffic volume. The proposed policies in the research included development of public transport and the increase of urban bus incomes and its effects on citizens' travel pattern (Liu et al., 2010).

Wang et al (2012) developed a system dynamics model to eliminate pollution of surface waters and wetlands (Wang et al., 2012). Torabi et al (2012) studied greenhouse gas emissions and pollutions caused by their pollution in Taiwan with system dynamics approach. They presented scenarios based on supply of electric motorcycles and limiting the supply of motorcycles by fossil fuels (Trappey et al., 2012). They examined the issue of urban transport in the cities in the 15-year time horizon. They considered air pollution as an effective variable in the traffic problem.

Their proposed policies included controlling traffic and thus reduce air pollution in cities, reducing travel demand through the development of e-government and optimum design of the city, reducing attractiveness of the use of private vehicles, and increasing the attractiveness of the system of public transport by reducing travel time. According to research conducted, the relationship among transformational variables, automotive industry variables, industries using home fuel and air pollution in metropolises was examined. The most important variables in this system can be traffic volumes, attractiveness of driving with private car, and developing public transport systems. Effective policies to reduce the level of air pollution in cities proposed in the model included plans for traffic control, development of highways plan, development of public transport, and ultimately limiting the activity level of polluting industries around the cities. Proposed model measured the effects of different policies of urban management in urban air pollution control and it was found that it can be used as a decision support tool by managers and decision makers in the urban management area.

2.1. Model description

In the model presented, air pollution of cities has been affected by three subsystems 1) industries pollution 2) urban transport pollution, and 3) pollution caused by domestic consumption. In order to limit the model border, the subsystem of pollution resulting from domestic consumption was considered as exogenous variable out of the main model borders, since its effects were largely foreseeable, and also uncontrollable. In order to simplify the model, subsystem of industries pollution was limited only to industries operating in the field of energy production and automobile manufacturing which have significant role in urban pollution, and pollution caused by other industry sectors was entered to model as exogenous variables. Then, each of the main subsystems is briefly described.

2.2. Industries pollution subsystem

This subsystem represents the effects of air pollution from industrial operation in the margin of the cities. The output of this subsystem is value of energy consumption in industry sector and industrial pollution. This last variable has direct impact on urban air pollution. Variables and the way of their impact on each other in this subsystem are shown in Figure 1.

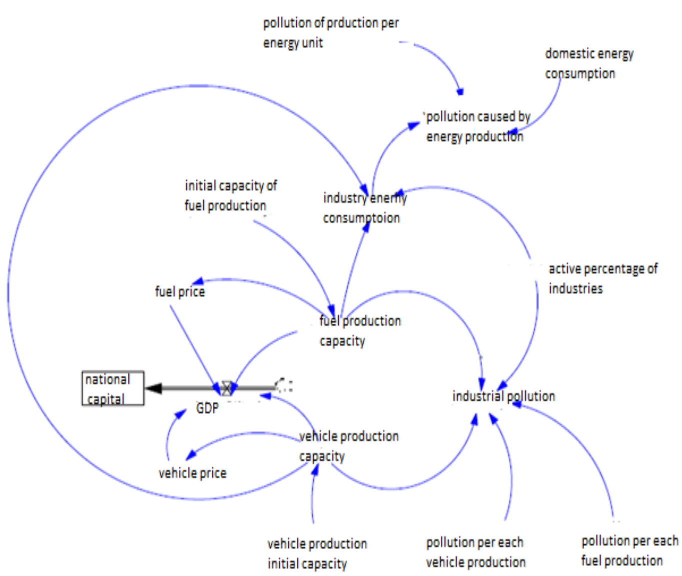

Fig 1. Industries pollution subsystem

The output of this subsystem is industrial pollution affected by vehicle production capacity, energy production capacity, and volume of pollution-producing industries, which produce pollution in countryside. Energy consumption in this industry and energy consumed in the automotive industry are fuel consumption determine energy consumption in the industrial sector. Domestic sector pollution in this model is modeled as an exogenous variable.

Urban transport pollution subsystem

This subsystem is divided to public and private transport subsystems.

2.3. Public transport subsystem

An influential variable in the subsystems of public and private transport and can be considered driving attractiveness. Changes of this variable in this subsystem are affected by two factors (1) investment in public transport (2) public transport fares. Increased investment improves the quality and thus increases the sense of security and the convenience of travel by public transport that it reduces attractiveness of driving. In contrast, increasing public transport fare leads to an increased number of travels using the urban vehicles.

However, income of public transport with an increase in the fares increases. The increase in income increases investment in public transport, and this increase will decrease the attractiveness of driving. The attractiveness of driving affects the variable of public transport attractiveness, so that reduced attractiveness of driving increases the attractiveness of public transport.

Figure (2) shows the loops affecting driving attractiveness in public transport subsystem.

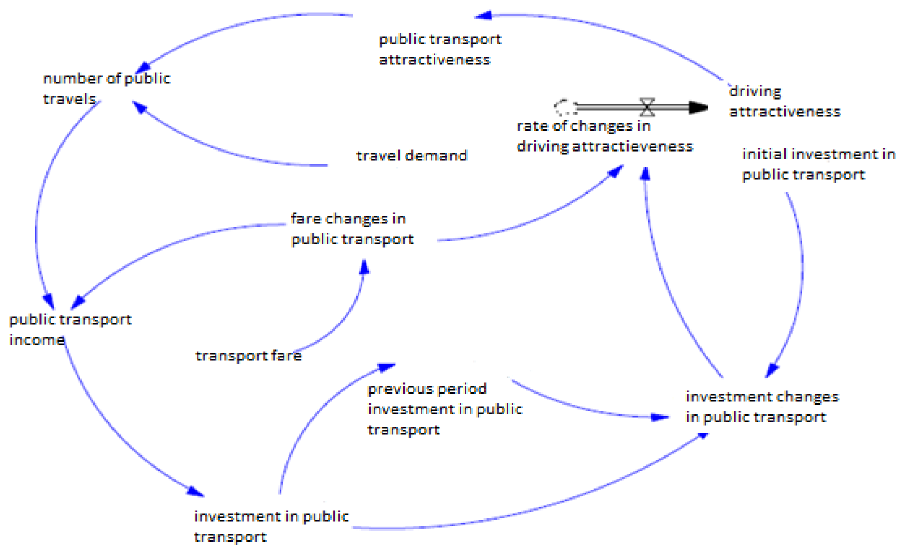

Fig 2. Public transportation subsystem

In this study, for simplification, it has been assumed that the amount of travel demand is fixed and constant. Increase in the attractiveness of public transport increases the public travels that this increase will increase the income of the public transport system.

2.4. Private transport subsystem

In this sub-system, two variables of travel time and traffic control designs have impact on the attractiveness of driving with private vehicles. In this subsystem, variable called traffic congestion was used that its behavior is under the influence of three other variables: (1) the capacity of the roads (2) the number of travels with the use of a personal vehicle (3) the length of the passages with the traffic plan. The length of the passages with traffic plan and the number of travel with the use of personal vehicles determine the another variable called as traffic congestion of passages with traffic plan.

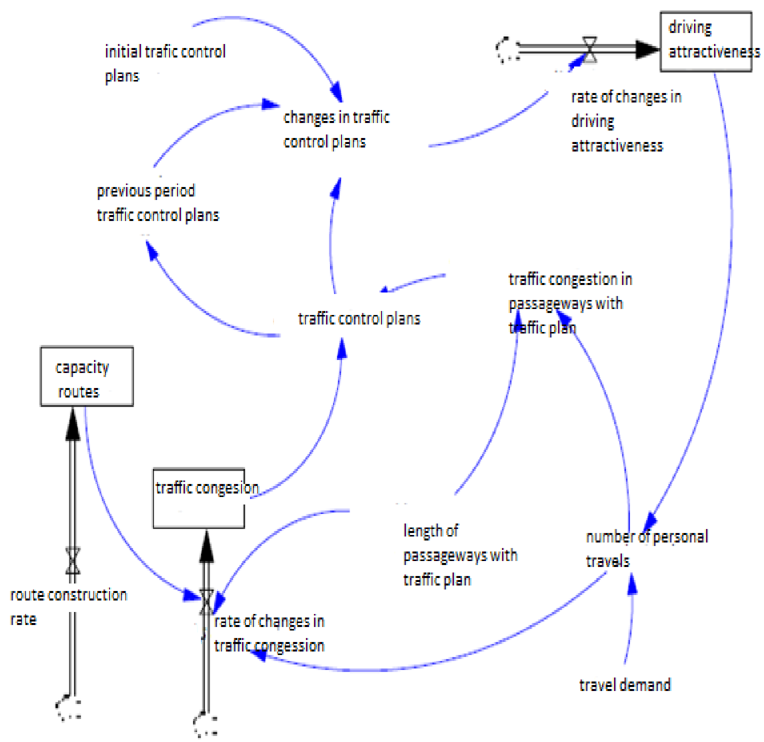

Fig 3. Private transport subsystem

As Figure 3 shows, the increase in traffic congestion in passageways with traffic or in other passageways would create or enhance areas or passageways with traffic control plan by city managers that this in turn could reduce the attractiveness of private vehicles, and eventually it reduces the number of travels by private vehicle.

Increased capacity of urban roads has also a significant impact on reducing travel time and it can increase the attractiveness of private cars. Figure 4 shows the combined effects of public and private transport in the model. As Figure 4 shows, the number of travels by public fleet has impact on traffic congestion.

Figure 5 shows the active subsystem in urban air pollution and the relationship between the two subsystems that are suburban industry pollution and urban transport pollution subsystem. According to the Figure (5), air pollution is a function of three variables, industrial pollution, pollution caused by energy consumption, and pollution caused by traffic, which description of each variable was expressed in the relevant subsystem.

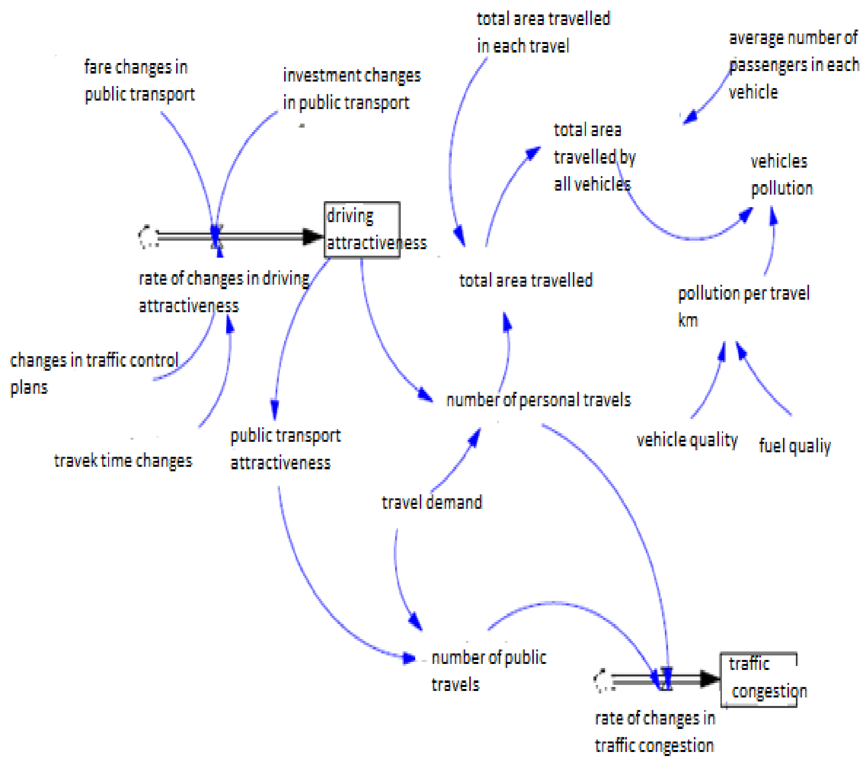

Fig 4. Simultaneous effects of private and public transportation systems

In order to study the role of existing pollutants in the metropolis, three main origins of pollution including traffic and volume of public and personal vehicles, pollutions caused by household consumption such as non-renewable wastes and pollutions caused by domestic energy consumption, and industrial pollutants including fuel and energy consumption and industrial pollution (industrial production waste and sewage) were examined. The important variables used in the flow and accumulation diagram mentioned in the form of a combination of the three causal diagrams are as follows:

Table 1: Status and flow variables and other model variables

status variable	Flow variable	Other variables
Traffic and volume of vehicles	Rate of enter to transportation system Rate of exit from transportation system	- Capacity of highway - Development of ways -Driving attractiveness - The number of personal travel -time of travel - the number of old cars - the adequacy of transport
Domestic pollutants	Pollutants rate Waste material rate	-urban waste -energy consumption - recyclable waste -non-recyclable waste
gross production	Production rate Pollutants production cost rate	-production capacity -Transportation Fuel consumption - industrial pollution -production waste and industrial sewage

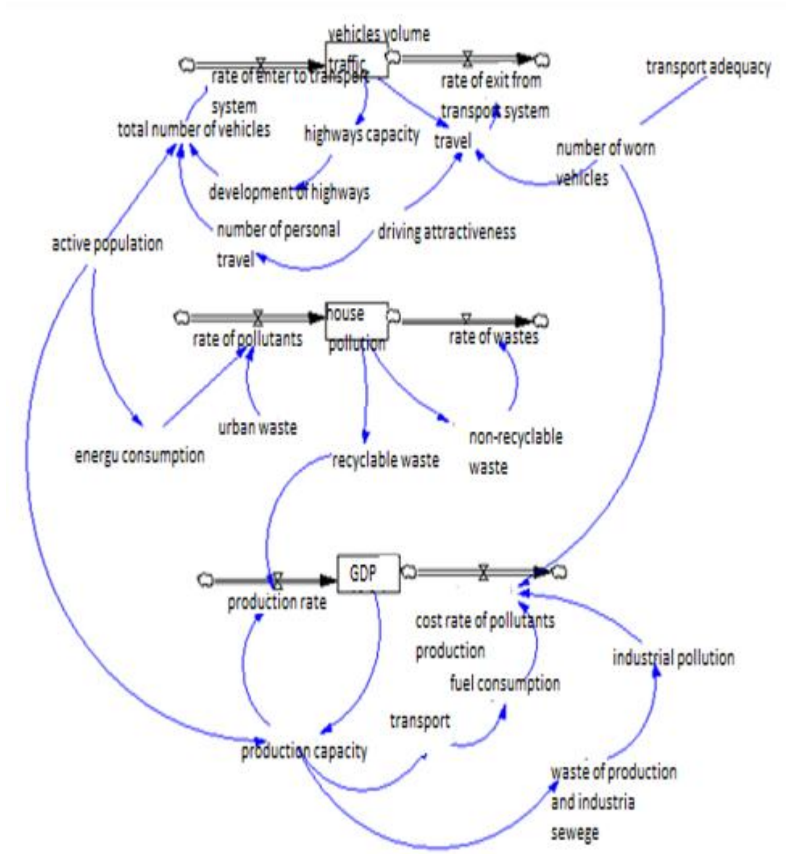

Fig 5. Cause and effect diagram of traffic and the volume of traffic, domestic pollutants, gross production (capital)

Based on the diagram (causal diagram), the level of traffic volume and vehicles volume are obtained by subtracting the rate of entry into the transportation system and rate of exit from it. The amount of the domestic pollution is difference of rate of pollutant materials and rate of waste and finally GDP that is an index for the industry.

After examining the causal relations between the variables, type of loops (positive and negative) was enhanced the relationship among other variables was determined. Finally, role of each of main factors of pollution was defined and explained in determining total pollution.

In the first loop, vehicles traffic and volume led to reduced capacity of highways and reduced capacity of highway leads to development of highways and the development of highways leads to number of vehicles and enter to transport system finally. In the second loop, traffic and volume of vehicles lead to reduced attractiveness of driving and increased attractiveness of driving leads to increased number of travel personally and this factor leads to increased number of vehicles and finally increased entry to transport system.

On the other hand, in the output of variable traffic status and vehicles volume, the increase in this variable increased travel time and finally reduced the rate of exit from transport system. In the loop related to traffic, transport adequacy and active population as exogenous variables play an important role in explaining the total number of worn vehicles and total number of vehicles. In the loop related to pollution of houses, the rate of this variable increased wastes and finally pollutants. The output of active population with energy consumption increases the variable of input rate.

On the other hand, the output pollution of houses is two variables of non-recyclable and recyclable wastes. Recyclable wastes increase the rate of production of industrial pollutant loop and non-recyclable wastes leads to increased rate of wastes, as active population indirectly increases the pollution of houses loop and congestion of vehicles volume. This factor has the same effect on gross production with positive impact on production capacity.

In the third loop, gross production as an indicator of industrial pollution leads to increased production capacity and this leads to increased production rate which it is the variable of gross production.

Production capacity leads to increased transport and this factor also leads to increased fuel consumption rate and ultimately increased the cost of production of the pollutants. On the other hand, production capacity leads to increase in industrial waste and sewage that leads to the production of industrial pollution and ultimately it is directly related to the rate of cost of pollutants production.

In the model, based on the structure of the effect of variables in the proposed model in Figure 5, it is found that as air pollution increases, more traffic plans become active and the variable of length of passageways with traffic plan increases.

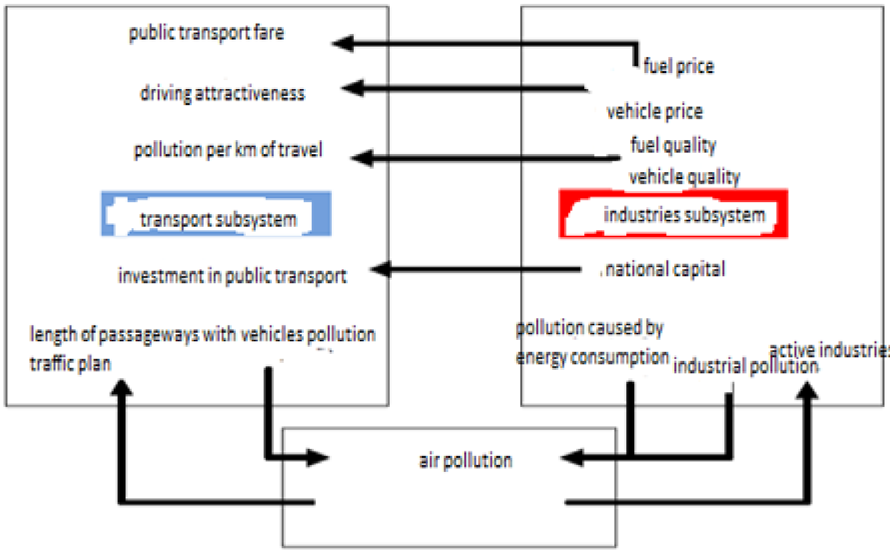

Fig 6. Overall view of the impact of variables in the proposed model

In addition, increased air pollution reduces the activity of pollutants activity and reduces the variable of active industries.

2.5. Implementation of model and results

All mathematical equations between variables of model were extracted according to environmental historical data model based on historical data, and traffic data, and so on. Mathematical equations were calculated based on statistical techniques and data mining such as correlation analysis, regression, and parameter estimation and finally they were entered to the final model.

The final model was implemented under three scenarios: (1) the best status, (2) the moderate status, and (3) the worst status. In the proposed model, developed policies and control variables to manage the system have been chosen as follows: (1) Controlling the rate of activities of polluting industries by manipulating the variables of the active rate of industries (2) improving the status of public transport by controlling the variable of investment in public transport (3) Changing the range of traffic plans by regulating the length of passageways with traffic plan. It seems that three above-mentioned variables as controlling leverages for urban managers and decision-makers can be effective in improving the level of air pollution. In different examined scenarios, each of three mentioned variables was entered to model under the best, moderate, and the worst statues.

The question is that how much each of these plans can be effective. The developed model responds to this question and thereby as a decision support model provides the conditions for urban managers to adopt correct decisions in improving city air quality.

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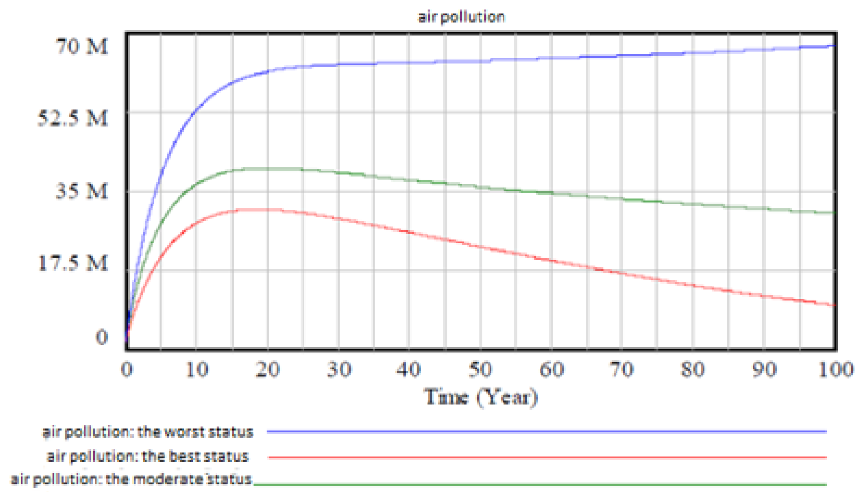

Fig 7. Changes in the variable of system (air pollution) status per three scenarios examined

According to Figure 7, it is found that in the moderate scenarios and the best status, the behavior of system status is descending, while in the worst scenario and the system status has a targeted behavior and almost after 30 days, the air pollution remains fixed at the relatively high level.

It could be stated that two scenarios of the best status and the moderate scenario can reduce pollution level of air in the long term, while the scenario of the worst status has merely the capability to control air pollution level at the certain level and prevent its increasing. Investigation of behavior of main variables of industry pollutant sub-systems shows that implementing the all of the policies of urban transport pollution reduces the activity of polluting industries in the short term but in the long term, pollution of industries will increase again (Figure 8).

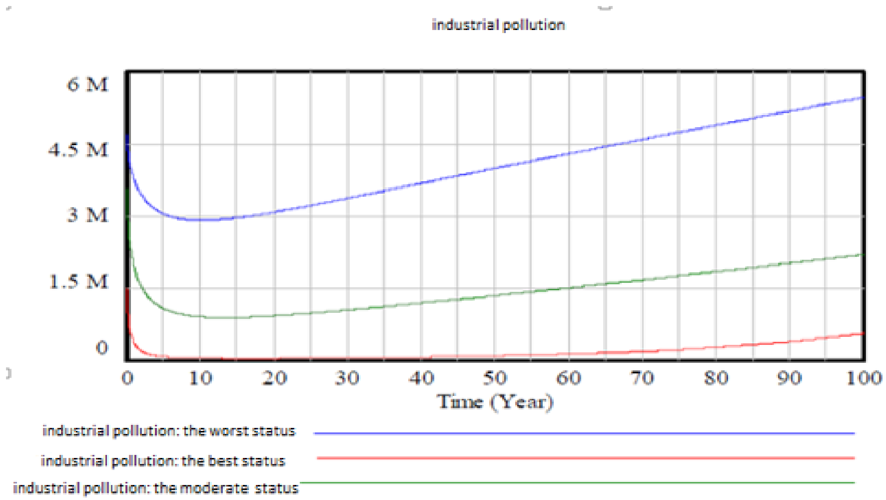

Fig 8. Changes in pollution volume of industries in three examined scenarios

In contrast, implementing the proposed policies reduces attractiveness of driving with personal vehicles, reduces traffic of passageways and in the long term, it reduces the pollution of urban transport system.

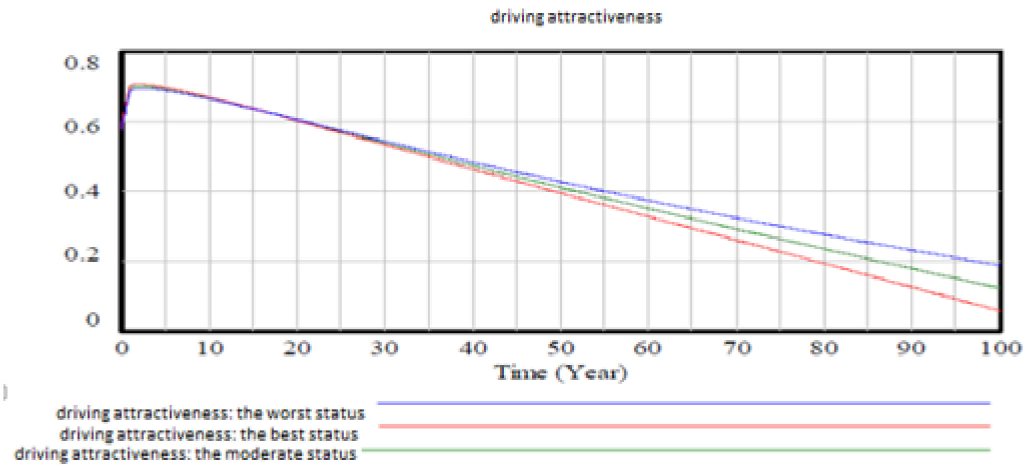

Fig 9. Changes in level of driving attractiveness in three examined scenarios

According to overall behavior of system status variable shown in Figure 7, it could be concluded that following implementation of policies introduced under the various scenarios, increase in pollution of industries is compensated by reduced pollution of urban transport and in the long term, the status of urban air pollution will improve.

In the proposed model, in order to model the process of natural decomposition of pollutants (by green space) and the air pollution transfer (by blowing wind), it is assumed that certain amount of air pollution in each simulated period exits from system. In conditions where pollutions decomposition and transfer are more than their production, air pollution level decreases. In this study, policies to increase the rate of decomposition by expanding urban green spaces have not been examined and the rate of decomposition of pollutions has been considered constant number, while policies of expanding the urban green spaces also can be considered as a key strategy in reducing air pollution.

According to existing challenges in development of the industries and economic risks resulting from suburb industries closure, expanding the urban green space can be studied as another strategy in reducing urban air pollution.

2.6. Review of systematic dynamics

Jay Forrester was the first developer of concepts that are known today as the systematic dynamics. These concepts were introduced for the first time in book entitled industrial dynamics (2010). These tools were developed based on the tools that control engineers used for analyzing mechanical and electric stability of control systems [13].

2.7. Model flow diagram

The main aim of these diagrams is to display the relationship among the variables of rate and level in a dynamic-system model. The variable of level indicates the accumulation of resources or values reflecting the system status. The variable of changing flow is a level variable in time interval that can increase or reduce the level variable. In addition, in this diagram, auxiliary variables and constant variables are used. By expanding the causal loop of the problem and adding level, rate and auxiliary variables, the flow diagram related to problem is developed. In the case of population, effective variables include birth rate, rate of immigration, and rate of death. Flow diagram has been shown in Figure 10.

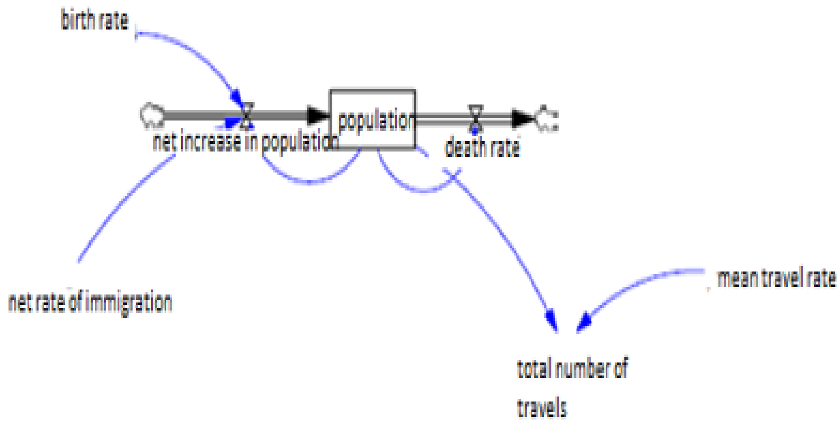

Fig 10. Population sub-system flow diagram

Population is the main determinant of number of travels that is obtained by multiplying in mean travel rate per each person. Different gases exit from a car cause air pollution, including NO family gases that the most common of them are NO2 and carbon monoxide (CO), sulfur dioxide, and ozone and particulates that are the major pollutants in the air in cities.

In this study, CO value was considered as the main pollutant gas. If the accumulated rate of CO is more than the allowed level, it will be effective in immigration and it reduces the rate of immigration. The rate of increase in this gas is the number of vehicles multiplied per each vehicle. By considering CO air pollution, the output in the flow diagram model can be shown as follows.

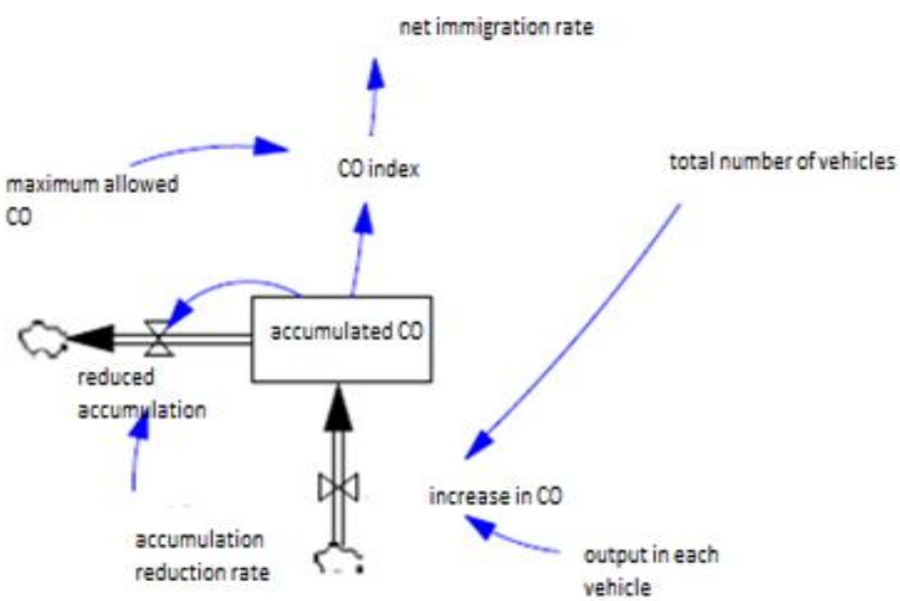

Fig 11. Follow diagram of air pollution sub-system

Estimation of parameters

To simulate the model, Tehran city data were used. After interviewing with experts and interpolation the existing information, other coefficients required to simulate the model are obtained. Table 2 shows the constant numbers used in the model and coefficients obtained by interpolation.

Table 2: Value of constant and estimated parameters

Parameter	Value	Unit
Birth rate	0.0140	/
Death rate	0.0021	/
GDP increase rate	0.02	/
Mean travel rate	3	Travel
Mean area travelled	8	Km
Investment per km	600000	Dollar per km
Travel capacity per km	5463	Travel
CO output for each vehicle	0.000235	Kg in vehicle pear year
CO capacity	5	Ppm
Rate of CO reduction	0.1	/
a coefficient	0.04	/
b coefficient	6e-8	/
c coefficient	6e-6	/
αcoefficient	-3.80962	/
βcoefficient	0.003	/

2.8. Model validation

To simulate model, the information of metropolises between 2011 and 2016 was used and to validate it, the data of years 2010 and 2011 were used. This comparison has been shown in Table 3. As the error rate in the examined cases is less than 2%, the model accuracy is acceptable. After confirming the validity of simulated model, we perform the simulation by considering one year interval for 50 years.

2.9. System simulation

After implementing the software for 50 years, the behavior of system and changes in its various variables are as follows:

Table 3: Comparison of real values and values obtained by model

Error percentage	Real value	Model output	Index
-0.294	8332246	8307810	Population 62 (million)
-0.038	84.2538	8399310	Population 75 (million)
-0.975	2749650	2722850	Number of vehicle 90
-1.296	2772830	2736900	Number of vehicle 82

Diagram 1 shows the changes related to population, death rate, and net increase in population, which they will increase during 50 years.

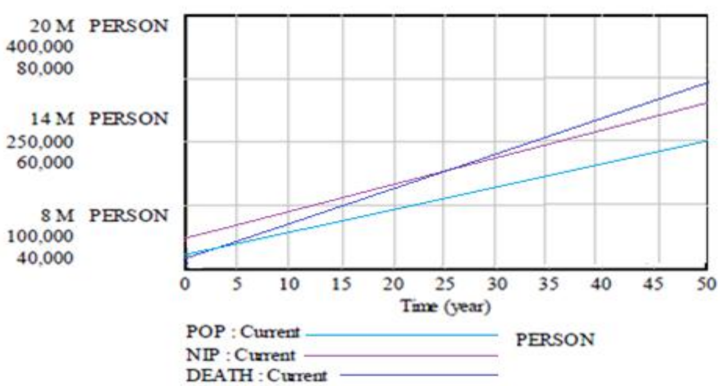

Diagram 1: Changes related to population, death rate, and net increase in population,

Diagram 2 shows the changes n rate of GDP and its increase rate simultaneously. In fact, it could be stated that the main factor in the city growth is the increase in GDP rate and consequently increase in per capita that increase both existing vehicle and rate of immigrations. By increasing the rate GDP, investment in transport increases.

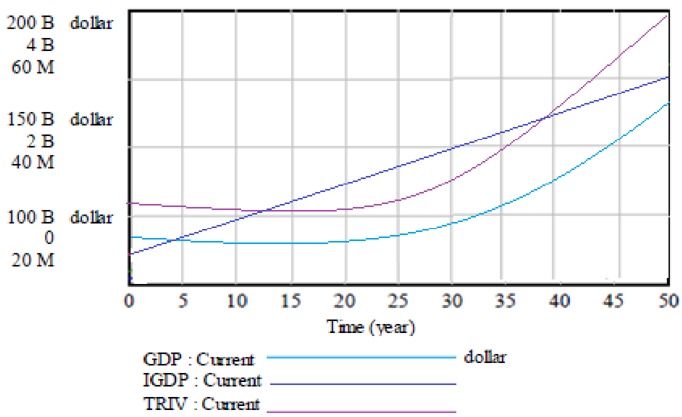

Diagram 2: Changes related to GDP and its increase rate and rate of investment in transport

Diagram 3 shows the rate of air pollution, per capita income, and total number of vehicles simultaneously. By increasing per capita income, the number of vehicles also increases, and consequently, by increasing the number of vehicles, air pollution also increases.

Diagram 4 shows that by increasing population, the number of travels increases. On the other hand, by increasing the GDP and more investment in transport, the capacity of transport lines increases. As a result, traffic congestion reduces slowly.

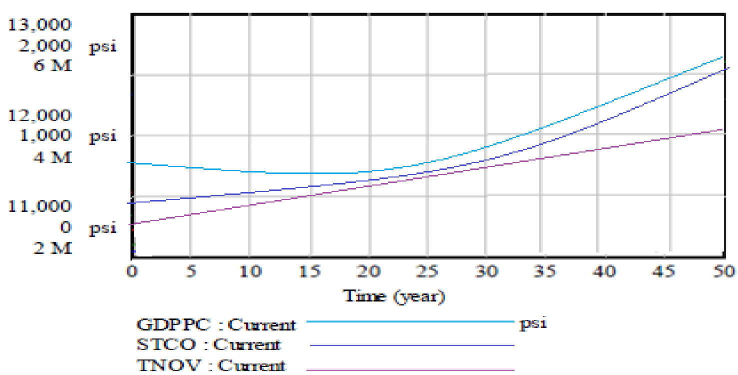

Diagram 3: Per capita changes, total number of vehicles and air pollution value

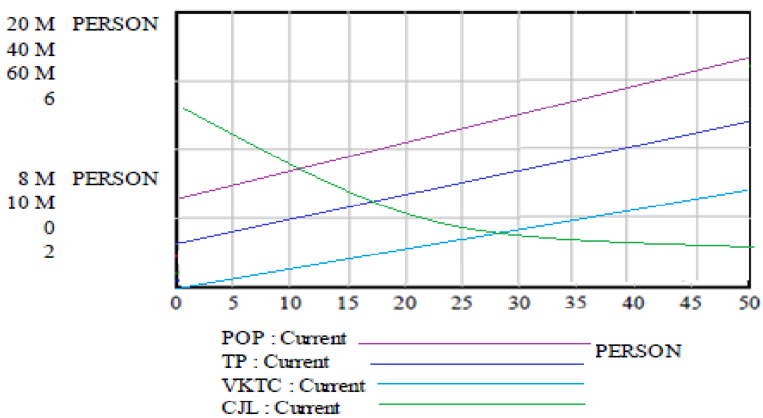

Diagram 4: The process of changes in population, number of travels, capacity of transport lines and traffic congestion

3. CONCLUSION

This study tries to use system dynamics approach to examine the problem of cities pollution and provide strategies using system dynamics. The existing model considers transport system, population, and environmental factors and GDP. As results of the model shows, by increasing the investment in transport lines, traffic congestion decreases. However, by reducing the factor of investment and reducing the people expectation of having personal vehicle, traffic congestion can be reduced by rational investment in the transport. It leads to reduced vehicle per capita and rate of pollutants.

REFERENCES

Armah, F.A., D.O. Yawson, and A.A. Pappoe (2010). *A systems dynamics approach to explore traffic congestion and air pollution link in the city of Accra, Ghana*. Sustainability, 2(1): p. 252-265.

Beckx, C., et al. (2012), *A dynamic activity-based population modelling approach to evaluate exposure to air pollution: methods and application to a Dutch urban area*. Environmental Impact Assessment Review, 29(3) p. 179-185-.

Jifeng, W., L. Huapu, and P. Hu,(2012). *System dynamics model of urban transportation system and its application*. Journal of Transportation Systems engineering and information technology, 8(3): p. 83 - 89.

Liu, S., K.P. Triantis, and S. Sarangi, (2010). A framework for evaluating the dynamic impacts of a congestion pricing policy for a transportation socioeconomic system. Transportation Research Part A: Policy and Practice. 44(8): p:608-596.

SADIK, A.-K. and M. EL-SOLH, GES AND PROSPECTS. 2014.

Schmidt, M. and R.-P. Schäfer, (2014). An integrated simulation system for traffic induced air pollution. Environmental Modelling & Software. 13(3): p. 303-295.

Sivacoumar, R., et al., (2013). Air pollution modeling for an industrial complex and model performance evaluation. Environmental Pollution. 111(3): p. 477-471.

Shahgholian, K. and H. Hajihosseini, (2013). A dynamic model of air pollution, health, and population growth using system dynamics: a study on Tehran-Iran (with computer simulation by the software Vensim). World Academy of Science, Engineering and Technology. 59: p. 245 - 252.

Szarka, N., et al., (2014). Atmospheric emissions modeling of energetic biomass alternatives using system dynamics approach. Atmospheric Environment. 42(3): p. 403 - 414.

Trappey, A.J., et al.,(2012). An evaluation model for low carbon island policy: The case of Taiwan's green transportation policy. Energy Policy. 45: p. 510-515.

Tseng, Y.-y., W.L. Yue, and M.A. Taylor. (2013). The role of transportation in logistics chain. Eastern Asia Society for Transportation Studies.

Vlachokostas, C., et al. (2014), Decision support system for the evaluation of urban air pollution control options: application for particulate pollution in Thessaloniki, Greece. Science of the Total Environment,. (23)407 :p.5937 - 5948.

Wang, Y-.C., et al., (2012). A system dynamic model and sensitivity analysis for simulating domestic pollution removal in a free-water surface constructed wetland. Water, Air, & Soil Pollution, 223(5): p. 2719 - 2742.