Research on Air Pollution Control Measures Based on System Dynamics ——A Case Study of Beijing

Cuiyou Yao*, Tingting Wang, Haiqing Cao and Yanhong Yang
School of Capital University of economics and business, Beijing 100070, China

*Corresponding author e-mail: 15222705896@163.com

Abstract. In this paper, we construct a system dynamics model of the air pollution control measures. Simulation experiments predict the trend of PM2.5 concentration under different conditions. The conclusions of the study are as follows: firstly, the urgent task of controlling air pollution in Beijing is strictly control the value-added of high energy consumption and high pollution industries as well as vehicle restriction. Secondly, advocating afforestation and increasing financial support. In addition, the new restrictions for the motor vehicles with foreign brands to be implemented in Beijing in 2019 has a significant effect on air pollution control.

1. Introduction
In recent years, air pollution has become one of the biggest environmental problems facing China. The 2017 China Ecological Environment Bulletin shows that among the days of severe pollution or more, the number of days with PM$_{2.5}$ as the primary pollutant accounted for 74.2%, PM$_{10}$ as the primary pollutant accounted for 20.4%, and O$_3$ as the primary pollutant accounted for 5.9%. Air pollution control has become one of the most important issues to be studied and solved.

Scholars have made a lot of beneficial discussions on air pollution control measures from the following perspectives. Some from the impact of air pollution, qualitative analysis of the problems existing in air pollution control at the present stage [1-4]. Some analyzed the causes of air pollution from the perspective of environmental science and proposed appropriate policy recommendations based on the analysis results [5-8]. The others started from the air pollution control policies of other countries and advanced regions to seek for reference [9-11]. However, there are few studies on quantitative evaluation of the effect of air pollution control measures. Assessment of air pollution control measures mainly focuses on the mass concentration of air pollutants monitored routinely. The change of air pollutant concentration before and after the implementation of air pollution control measures was analyzed. In fact, air pollution control involving all aspects of the economy and society, is a systematic project. This paper intends to explore the impact of relevant measures on air pollution control from a systematic point of view. The influence of different measures on the reduction of representative air pollutant concentration was quantitatively simulated through the establishment of corresponding system dynamics model, as well as the impact of the new restrictions to be implemented in Beijing in 2019 on air pollution control. Based on the simulation results of the system, we propose some suggestions.
2. Model building

2.1. Causal loop diagram

According to the 2017 Beijing state of the environment bulletin, PM$_{2.5}$ has become the main air pollutant in Beijing. Therefore, the effect of air pollution control defined in this paper refers to the change of PM2.5 year-average concentration after the implementation of different control measures. The causal loop diagram is shown in figure 1.

![Figure 1. Causal loop diagram.](image)

2.2. System stock flow chart

By analyzing the causality among variables, the meanings of stock, flow and auxiliary variables in system dynamics are combined. The stock flow chart of the system is listed in figure 2.

![Figure 2. The stock flow chart of the system.](image)
2.3. Comparison of actual and simulated values
The system dynamics model itself has some limitations and the real system involves many factors. Considering the feasibility of the research and the availability of the data, the key variables are inevitably selected in the research process. Therefore, this paper uses trend consistency to test, focusing on predicting the future development trend of key variables and adjusting the model according to the simulation results. By analyzing the results, we know that the model can truly reflect the real system.

3. Model simulation and regulation

3.1. Model regulation
The system dynamics model of major air pollution control measures in Beijing has been built and the accuracy of the model has been tested. The next step is to simulate the model. In this paper, the simulation time limit is set from 2011 to 2025 and the simulation time limit is set from 2020 to 2025 when investigating Beijing's new restrictions implemented from November 2019, with a time step of one year. Six air pollution control measures are selected in this paper, including: advocating afforestation, strictly control the value-added of high energy consumption and high pollution industries, increasing financial support, enhancing scientific and technological innovation, elimination of yellow label car within a time limit and vehicle restriction.

3.2. Comparative simulation analysis
The most intuitive manifestation of air pollution control is the decrease in pollutant concentration in the air. Therefore, this paper studies the effects of air pollution control measures based on the change of PM2.5 concentration after the implementation of relevant measures. The variation trend of PM2.5 concentration under different control measures is shown in figure 3.

As can be seen from figure 3, compared with other pollution control measures, strictly control the value-added of high energy consumption and high pollution industries has the most significant effect on the reduction of PM2.5 concentration. Secondly, vehicle restriction policy. Thirdly, advocating afforestation, increasing financial support, elimination of yellow label car within a time limit and enhancing scientific and technological innovation.

On June 15, 2018, the Beijing municipal commission of communications, the public security traffic management bureau of the Beijing public security bureau et al issued a notice on traffic management
measures for some passenger cars. From November 1, 2019, traffic management measures will be taken for passenger cars licensed by provinces, districts and municipalities (including temporary number plates) on the roads in some administrative areas of the city. In this paper, we simulate the implementation effect of the new restrictions from 2020 and investigate the effect of the implementation of the new restrictions on PM2.5 concentration. The simulation results are shown in figure 4.

![PM2.5 concentration](image)

**Figure 4.** Difference of PM2.5 concentration between the new restrictions and without new restrictions.

As shown in figure 4, compared with the current situation, the implementation of the new restrictions will reduce PM2.5 concentration. The difference of PM2.5 concentration will increase over time, indicating that the new restrictions has a long-term effect. The new restrictions mainly aimed at vehicles traveling in Beijing in foreign ports, which is constrained by the Beijing trumpet. Many residents in Beijing have dealt with foreign license plates to solve the problem. Since the comprehensive urban carrying capacity and road traffic carrying capacity are limited, the implementation of the new restrictions is of great benefit to alleviate urban traffic congestion and control air pollution.

4. Result analysis

Based on the data of Beijing, this paper constructs a system dynamics model and simulates the corresponding measures of air pollution control. We found that strictly control the value-added of high energy consumption and high pollution industries, vehicle restriction, advocating afforestation and increasing financial support have significant effects on air pollution control in Beijing. Elimination of yellow label car within a time limit has certain effects on the air pollution control in Beijing. However, the impact of enhancing scientific and technological innovation in air pollution control on the reduction of pollutant concentrations is limited. The results show that the implementation of the new restrictions mainly aimed at the foreign port brand motor vehicles has a significant impact on the reduction of PM2.5 concentration.

In particular, the simulation results show that strictly control the value-added of high energy consumption and high pollution industries have the most significant impact on the control of air pollution in Beijing, followed by vehicle restrictions. However, after 2023, the simulation curves of strictly control the value-added of high energy consumption and high pollution industries and vehicle restriction intersect. After the intersection, the policy of vehicle restriction has the most significant impact on air pollution control in Beijing, followed by strictly control the value-added of high energy consumption and high pollution industries. The reasons may be as follows: On May 14, 2018, Beijing released a new round of research results on source apportionment of PM2.5. According to the
characteristics of PM2.5 in Beijing's current local atmosphere, mobile sources account for 45%. Beijing has implemented the relevant policies of banning yellow label car since 2009 and the related policies of eliminating yellow label car have been implemented one after another. Since the mobile source accounts for 45% of the local atmospheric PM2.5 source in Beijing and the diesel vehicles driving in Beijing have the greatest contribution to the mobile source, the elimination of the yellow label car within a time limit has a long-term impact on the air pollution control in Beijing. On the other hand, in 2018, the proportion of added value of tertiary industry in Beijing was 81% and that of added value of secondary industry was 18.6%. High energy consumption and high pollution industries are mainly secondary industries. However, the proportion of added value of secondary industry in Beijing is relatively small, which may lead to the effect of vehicle restriction on air pollution control in Beijing is better than that of strictly control the value-added of high energy consumption and high pollution industries.

5. Policy implications
Under the background of accelerating urbanization process, how to better control air pollution? According to the research results, the policy implications of this paper are as follows.

5.1. Strictly control the value-added of high energy consumption and high pollution industries
The elimination of backward production capacity with high pollution plays an important role in improving the industrial structure upgrade rate. Therefore, when controlling air pollution, we should strictly control the value-added of high energy consumption and high pollution industries.

5.2. Actively implement the motor vehicle tail number restriction policy
Rationally setting the ratio of vehicle tail number restriction to reduce vehicle traffic volume. Reasonable tail number restriction can reduce the amount of motor vehicle travel, alleviate traffic congestion and improve air quality.

5.3. Advocating afforestation and increase the coverage of urban greening
Green plants are called "natural dust collectors". They can absorb harmful particles such as carbon and sulfide in smoke and dust. Advocating afforestation and creating a harmonious and livable new city will help alleviate air pollution.

5.4. The government should increase financial support and encourage social capital to invest in air pollution control.
Increasing government financial support can improve the level of air pollution control. PPP financing pattern can be introduced to attract social capital to participate in air pollution control. The government and social capital conclude contracts in accordance with the principle of equal consultation and social capital undertakes most of the work carried out by air pollution control measures. The income of social capital can be derived from: sewage charges of industrial enterprises, excessive emission of motor vehicle exhaust emissions and congestion charges of road sections.

5.5. Actively implementing the new restrictions for vehicles with foreign brands
The implementation of the new restrictions policy can improve the air quality of Beijing in the next few years and ensure the fairness and effectiveness of the total motor vehicle regulation policy. Therefore, we should actively implement the new restrictions on motor vehicles with foreign brands.

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