JOURNAL OF TRANSPORTATION
SYSTEMS ENGINEERING AND INFORMATION TECHNOLOGY
Volume 8, Issue 2, April 2008
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this paper as: J Transpn Sys Eng & IT, 2008, 8(2), 80−84.

RESEARCH PAPER

Optimal Total Vehicle Pollutants Emission Quantity Based on Link Traffic Capacity Constraints

ZHU Zhigao, LI Tiezhu*, LI Wenquan

College of Transportation, Southeast University, Nanjing 210096, China

Abstract: With the growing of vehicles ownership, the vehicular exhaust emissions have become major sources of air pollution in cities. In this paper, the pollutants, carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbon (HC) are considered as evaluation factors. On the basis of the relation between the emission factors and vehicle's velocity and the relation amongst three parameters (Volume, Speed, and Density) of traffic flow, we have designed a model. This calculates the total quantity of pollutants emission from vehicles based on speed, proportion of vehicle types, and traffic volume. Using the theory of nonlinear programming, we have formed an optimal model in which the link capacity is one main constraint and the minimum of the total quantity of pollutants emission is the goal and designed its algorithm solution. The aim of our research is to find a method to control the quantity of traffic pollutants emission through adjusting and controlling the composition of vehicle types, and then the traffic volume and vehicle's running speed indirectly. Finally, the feasibility of the model is justified through a practical example.

Key Words: single vehicle emission factors; pollutants emission quantity; traffic capacity; traffic volume; vehicle speed

1 Introduction

The impacts of urban traffic on the natural environment are atmospheric pollution, noise pollution, and ecological pollution.[1] With the rapid growth of vehicles ownership, the emissions exhausted by vehicles have become a public calamity for the atmosphere, harming people's health, and destroying the balance of natural ecology. According to the sorted statistics of sources of urban air pollutants, in most large cities in China, around eighty percent of pollutants come from traffic emissions[2]. According to statistics in Beijing, in over seventy percent of streets the carbon monoxide (CO) concentration and the nitrogen-oxygen compounds (NO_x) concentration exceed the national standards almost every year. Even along the second ring road, the third ring road, and other sections of roads, which have higher average speed, the nitrogen-oxygen compounds (NO_x) concentration also exceed the national standards.

The control and reduction of the traffic pollution has become one of the main focus of research on sustainable traffic development. There are three aspects of research on traffic emissions in domestic and international field. First is the vehicle emission factors model that has broad application in domestic and international field, such as the MOBILE[3] model that was designed by United State Environmental Protection Agency and comprehensive modal emission model[4], CMEM. The latter was designed by the University of California, Riverside. The Beijing Jiaotong University, Southeast University [5−7], and others[8−11]have carried out a lot of related research. The second aspect of research on traffic emissions is the traffic pollutants dispersion model, such as the California line source dispersion model, CALINE3 and California line source for queuing & hot spot calculations, CAL3QHC[12] model designed by the California Department of Transportation. The other example is the operational street pollution model, OSPM[13] designed by Denmark's National Environment Research Institute. The third aspect of research on traffic emissions is the transportation planning, the control, and management of traffic on the impact of traffic emissions [7,14−16].

The control of transport system emissions of air pollutants is by reducing motor vehicle emissions through the improvement of engine control technology, and to reduce emissions quantity through controlling the operation of traffic

Received date: July 16, 2007; Revised date: Dec 10, 2007; Accepted date: Dec 24, 2007
*Corresponding author. E-mail: litiezhu@seu.edu.cn

flow. Therefore, in this paper, CO, NO_x, and HC are considered as pollutant evaluation factors. Using the theory of nonlinear programming, we have designed the optimization model of total pollutants emission to explore the relationship amongst traffic structure, traffic volume, and optimal total of pollutants emission under the condition that satisfies the actual traffic demand and the link capacity.

2 Vehicle emissions analysis on road

2.1 Traffic flow characteristic analysis

Urban roads are main the main infrastructure for urban transport; first they should meet the function of transportation requirements, and also play an important role in organizing city and urban land use[17]. Traffic on urban roads is related to the grade of urban roads and the region where the roads locate. Under normal circumstances, different levels of urban roads have different traffic volume and traffic structure. The traffic volume on urban roads has the characteristics of varying with time, such as hour, week, and month. Except for the determination of traffic control measures, traffic composition usually includes all vehicle types. If the impact of intersections is not considered, then the speed on links mainly relate to the traffic volume.

2.2 Emission factors

The pollutants from urban traffic exhaust emissions include CO, NO_x, HC, PM, SO_2, and RCHO. In China, according to the standards for light vehicle exhaust emissions (GB 14761.1-93) and for automotive gasoline engine exhaust emissions (GB 14761.2-93), CO, NO_x, and HC are experimental certification test factors and products checked the consistency test factors. Therefore, CO, NO_x, and HC are considered as the pollutants evaluation factors.

In GB5181-58 (The People's Republic of China's national standard), the emission factors called quality emission are the average levels of exhaust emissions under the influence of all factors. The level of emission is affected by many factors like the design of vehicles, the manufacture characteristics (such as the engine type and the level of technical, collocating and working conditions of emission control equipments), the level of mechanical conditions, and inspection and maintenance of vehicle engines. In addition, the use of oil plants, the quality of fuel, the effect of inspection and maintenance,, the characteristic of traffic flow (including composition, service condition, age), and the performance of vehicles (altitude, temperature, humidity, condition of the road and vehicle mix)[14] affect the level of emission.

In the domestic and international field, research indicates that the single vehicle emission factors are sensitive to speed [7,10,11]. The average speed of vehicles has relatively large difference in different cities, thus, when providing vehicle emission factors their average speed has to be considered. At the same time, the total pollutants emission quantity by traffic flow is related to traffic volume, traffic composition, and mileage.

3 Optimization model

3.1 Model introduction

On the basis of the relationship amongst single vehicle emission factors, speed and traffic flow parameters (volume, speed, and density), we set up a model of pollutants emission quantity on link amongst three parameters i.e. speed, proportion of vehicle types, and traffic volume. In this model, the main constraint condition is link capacity; in addition, the actual proportion of vehicle types in traffic flow is also considered, and its goal is to minimize the total pollutants emission quantity. This model can be translated into a math optimization problem

$$\text{Min} \quad f(x), x \in R^n \tag{1}$$
$$\text{s.t.} \quad g(x) \geq 0$$

where $J(x)$, $g(x) = (g_1(x), g_2(x), \cdots, g_s(x))^T$, $g_i(x)$ (i=1,2,···,s) are real function in the set X, and $X \subset R^n$ .Function $f(x)$ represents the total pollutants emission quantity, which relates to the single vehicle emission factors, traffic volume of various vehicle types, and the length of link. Function $g(x)$ is the column vectors that represent constraint conditions, i.e. capacity, proportion of vehicle types, and traffic volume that is a nonnegative integer.

3.2 Modeling

A road is given, whose basic length is L (km), number of lanes is N, traffic volume of vehicle type j is V_i and traffic volume in passenger car unit (PCU) is V^{PCU} (pcu/h)[18]. Then,

$$V^{pcu} = \sum_{j=1}^{m} V_j \alpha_j \tag{2}$$

where α_i is the PCU equivalent for vehicle type of j; m is the total number of vehicles' types.

Under a certain traffic performance condition, total k pollutants emission quantity exhausted by vehicle type j is PR_{jk} (g/h). Then,

$$PR_{jk} = EF_{jk} V_j L \ . \tag{3}$$

where EF_{μ} is the emission factor of k pollutants exhausted by vehicle type j, g/(veh·km); the means of other symbol has been given before.

The total k pollutants emission quantity is PR_k (g/h):

$$PR_{jk} = EF_{jk} V_j L \tag{4}$$

On road, under certain traffic performance conditions, the total pollutants emission quantity is Q_L(g/h):

$$PR_k = \sum_{j=1}^{m} PR_{jk} \tag{5}$$

where ω_k represents k pollutants' weight which reflects k pollutants' harmfulness to environment, which can be attained by relevant research (if their harmful degrees are equivalent,