韓國地形空間情報學會論文集 第8卷 第1號 2000年 3月 pp. 13-25

도로교통관련 대기오염평가 GIS지원시스템

GIS-supported Evaluation System for Road Traffic-related Air Pollution

표 명 영*

Pior, Myoung-Young

要 旨

도로교통환경문제는 현대의 도시생활에 있어서 세계공통의 심각한 환경문제의 하나이다. 본 연구에서는 도로교통환경문제, 특히 도로교통에 기인하는 대기오염문제의 평가를 위한 지원시스템을 개발하였다. 본 개발시스템은 GIS, 교통관련의 대기오염시뮬레이션모델, 예비적 대책들의 데이타베이스로 구성되어 있다. 대기오염시뮬레이션모델의 구축에 있어서, GIS지원환경은 연구대상지역의 대량의 공간정보의 처리와 실제위치상에서의 보다 정확한 대기오염의 계산이라는 점에서 유용한 툴(tool)을 제공할 수 있다. GIS지원시스템의 이러한 역할은 보다 효율적인 분석과 보다 합리적인 결정을 위하여 매우 유용한 것이다. 본 연구에서 개발된 시스템의 실용성은 이집트 카이로시의 도시권을 연구대상지역으로 적용함으로써 그 가능성을 확인할 수 있었다.

ABSTRACT

Road traffic-related environment problems has become now serious problem common in the urban life throughout the world. In this study, a GIS-supported evaluation system has been developed for dealing with the road traffic-related environment problems, especially focusing on air pollution in the urban areas. The developed system consists lof three essential parts: GIS; traffic-related air pollution simulation model; and the database for potential strategies. In establishing the simulation model, a GIS-supported environment can provide a useful tool for handling a wide range of data characterizing study areas and for preparing more accurate estimation on real locations. Such roles of the GIS-supported system can be helpful to more efficient analysis and more reasonable decision-makings. As a preliminary stage in developing the system, the metropolitan area of Cairo in Egypt was applying into being as a pilot study to test the potentiality of the prototype system.

1. INTRODUCTION

1.1 Background

Throughout the world, urban areas are developing at rapid pace and the growing levels of motorization have inevitably led to traffic-related environmental problems. Among traffic-related environmental issues in urban environment, air pollution is generally considered as one of major sensitive problems.

The relative contributions to air pollutant emissions from mobile and stationary sources differ markedly among urban areas, depending

* 일본 명해대학교 부동산학과 조교수

on their circumstances. Air pollution factors have interactivity within or with the other factors: mobile sources; stationary sources; natural conditions (geographical and meteorological conditions); social awareness levels to air pollution problems; and so on. The symptoms of air pollution are the results of such complicated interactive processes.

These days, the contribution to air pollution by the transport is exacerbated by the rapidly rising demand for automobiles. As the air pollution problems are accompanied with traffic congestion, the traffic-related environmental problems have been increasing, especially in urban areas of the developing countries. Based on regional view, such traffic-related environmental problems cause hurdles to economical growth, result in poor amenities in urban living and damage to citizen's health. They also influence on the global warming problem. The WHO Commission on Health and Environment (WHO, 1992), which recently concluded its work, identified urban air pollution as a major environmental heath problem deserving high priority for action. (WHO/UNEP, 1992).

Considering these facts, the management of road traffic-related environmental problems should be taken as a matter of urgency in those urban areas where strategies are weak or non-existent. The benefits of local air pollution abatement may not only be limited to reduce air pollution alone. Substantial benefits could also occur in the form of checking global warming problem and reducing traffic accidents or congestion.

Under these circumstances, a more convenient tool is needed for the evaluation of urban strategies to cope with traffic-related air pollution problem. An efficient and comprehensive tool to support decision making is indispensable. In developing a more convenient tool, the advantages of GIS are fully utilized in this study. All urban and transportation planning data are intimately related to geographical locations. GIS is the geo-referencing information system. For that reason, a wide range of geo-reference data required in the simulation process of air pollution can be efficiently handled and the state of air pollution can be accurately simulated on real locations. In this way, GIS-supported environments will offer a useful tool for more reasonable evaluation of potential strategies.

Considering these factors, the author tries to develop a GIS-supported system for dealing with road traffic-related environment problems, especially focusing on air pollution problem.

1.2 Objectives

Given the explanation in the background, the main objectives in this study are as follows:

1) By developing a GIS-supported evaluation system, the author will provide a convenient tool for supporting the evaluation of potential strategies that are designed to improve traffic-related air pollution problem.

2) By applying the proposed system the metropolitan area of Cairo in Egypt as the study area, the author verifies the potentiality of the prototype system for practical application.

2. THE STRUCTURE OF THE GIS -SUPPORTED SYSTEM

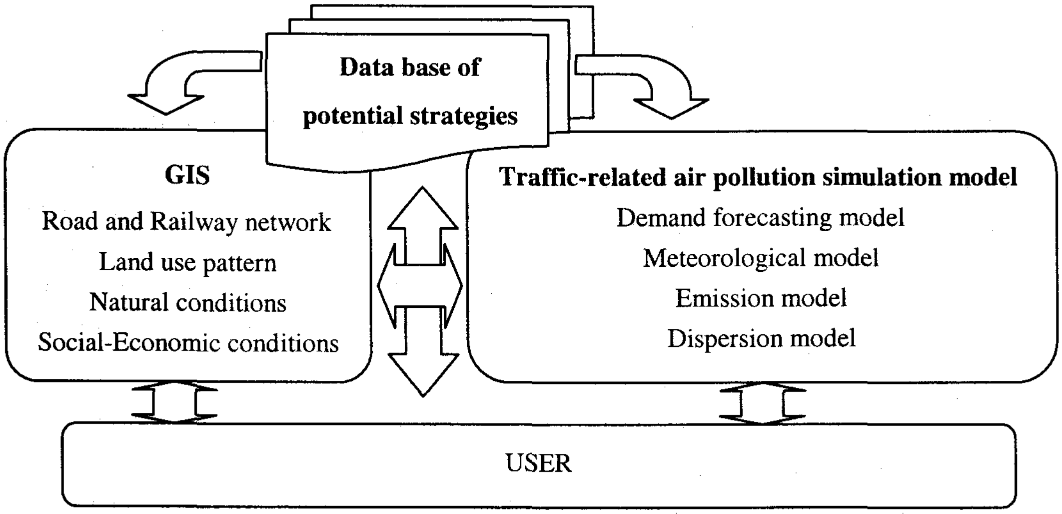

figure 1 Overview of the proposed system

2.1 Overview of the system

The system developed in this study consists of three essential parts: GIS; a traffic-related air pollution simulation model; and the database of potential strategies that are planned or suggested as the solution of air pollution problem.

GIS plays a basis role in the proposed system. In GIS, spatial data and their attributes for the evaluation process are managed by the DBMS (data base management system) of GIS. The simulated outputs are also reported, displayed and plotted through GIS.

In the simulation model, the conditions of air pollution are simulated with the models based on demand forecasting, meteorological factors, pollutant emission, and pollutant dispersion. Spatial data and their attributes necessary for the models are simulated via updating, storing, and retrieving within GIS-supported environment.

In the database of potential strategies, some strategies are selected as options among planned or suggested solutions in study areas. Depending on the selected options, the input variables to the simulation models are altered. Different strategies can lead to different outputs. At the last stage, the relative effects of different kinds of potential strategies are evaluated by comparing the simulated outputs.

The conceptual framework of this GIS-supported system proposed in this study is shown in Figure 1. The prototype system, including GIS, was coded by Visual Basic as a program language in this study.

2.2 Advantages of the GIS-supported system

In the traffic-related air pollution simulation process, a wide range of data characterizing study areas must be required. Features of the natural environment (e.g., topography, meteorological conditions, etc.), the traffic-related data (e.g., road network, railway network, traffic-volume of each link and each traffic mode, the attributes of road and railway, etc.), social-economic-conditions (e.g., population distribution, zonal activities, etc.), and land use pattern are served as examples. Since such data are directly managed within the GIS-supported environment, the burden of collecting and coding spatial information can be reduced. As an example of the use of GIS-supported environment for simulation model, the equations of (2-3) and (2-4) that determine the air pollution concentration at (x, y, z) are directly calculated by using geo-reference system of GIS. The determination of minimum travel time or shortest path necessary for demand forecasting model is also efficiently calculated by using the network analysis function of GIS. From this viewpoint it is very convenient to simulate any strategies before establishing a final scheme within GIS-supported environment.

The need for estimating air pollution on real location is one of the important issues in managing the air pollution problem. In the GIS-supported environment, the spatial distribution of air pollution is directly displayed and plotted for real locations. The study results can also be displayed with any variety of spatially detailed or zone specific data. These functions make it more convenient for interpretation and explanation for affected residents or public representatives.

By using the overlay function of GIS, air pollution concentration data and population distribution data can be simultaneously analyzed. The output of this analysis can help to easily find the number of people exposed at each level of air pollution and to reasonably evaluate some decisions for reducing human exposure to air pollutants.

These advantages are useful for necessary analysis and can help policy-makers to perform traditional tasks both faster and better.

2.3 Air pollution monitoring data

Monitoring data can explore the current state of air pollution and provide verification of the appropriateness of the simulation model. In the proposed system, the six air pollutants are nominated as high priority air pollutants. They are concretely CO, $NO_X(NO_2)$, O_3/Photo-oxidants, SO_2, SPM (suspended particulate matter) and Lead. For identifying the comprehensive situation in study areas, most of the data on six air pollutants explained above are required. In the developing countries, however, the existing data continually monitored by authorities is very limited. In such cases, new air pollution data are monitored by a simple survey method for this study.

The simple survey method has been provided to facilitate an on-site probe of the state of air pollution by measuring concentrations of air pollutants at some representative sites to supplement the existing data. As an example of simplified measurement equipment, the equipment for NO_2 consists of a scavenger unit fitted with T.E.A-impregnated paper filters exposed to the atmosphere for a fixed period (1-30 days). For a simple survey of the concentration of air pollutants, the equipment is placed at representative locations of a study area for a few days. After recovery, the filters are immersed in a color developer and their light absorption characteristics measured. The simplified measuring equipment gives the values within 10% of those obtained with well-maintained measuring equipment located in an environmental monitoring station in Japan (Japan Transport Cooperation Association, 1995). So, the simple survey method has enough partial accuracy for understanding the real air pollution situations.

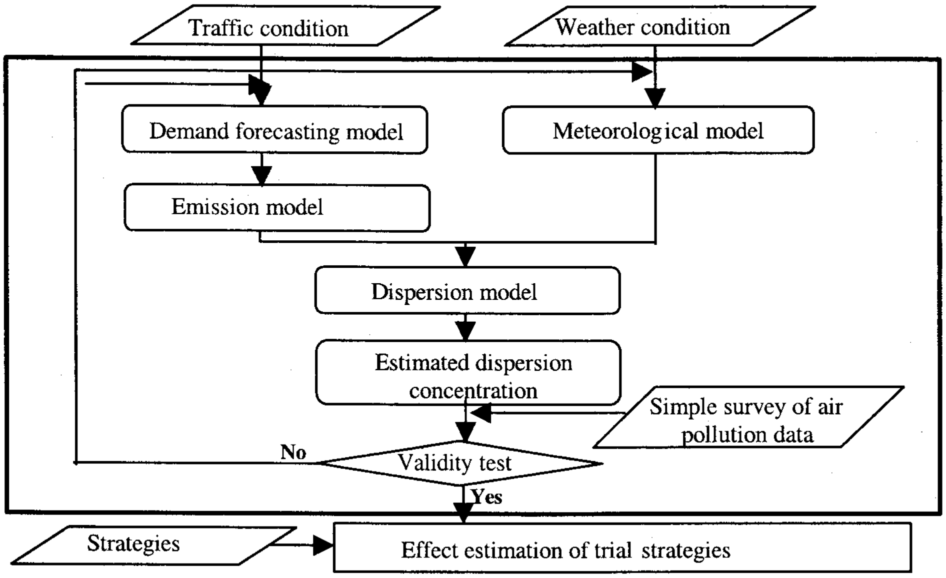

Figure 2 Flow chart of traffic-related air pollution simulation model

2.4 Traffic-related air pollution simulation model

A simulation model for traffic-related air pollution can forecast the future situation, as well as estimate the present situation in study areas. This section provides an overview of the general structure of the simulation model that is integrated with GIS.

The simulation model is composed of four major components: a demand forecasting model; a meteorological model; an emission model; a dispersion model. These components are briefly described above in Figure 2, which shows a simple flow chart of the model.

2.4.1 Demand forecasting model

The demand forecasting model is used to simulate the spatial distribution of traffic activity. This model is an adaptation of the conventional 4-step demand forecasting model (trip generation, trip distribution, modal split and network assignment) that is widely used by transportation planners. These components are also briefly described in Figure 3.

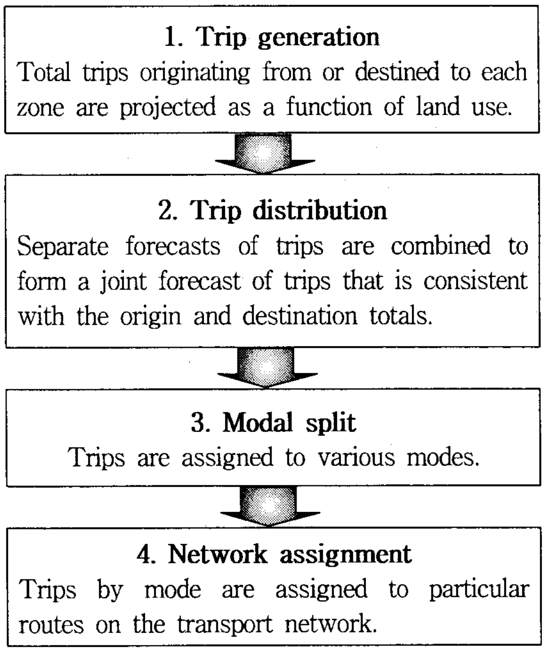

Figure 3 Simple flow chart of demand forecasting model

The final outputs of these steps are the numbers of each vehicle type and average speeds on each road section. These outputs are then used as inputs to the emission model.

2.4.2 Emission model

After the demand forecasting model, emissions of pollutants from mobile sources are calculated by the emission model.

The inputs to the emission model are the numbers of each vehicle type and the average traveling speed on the link. Emissions are determined by the traveling speed and the characteristics of vehicles. Several reports published by transport-related institutes carry the information on the relationship of emissions with the traveling speeds and the types of vehicles. For developing the prototype system in this study, the relationship of emissions per kilometer with the speeds and the types of vehicles is based on the functions compiled by Nitrogen Oxides Concentration Operation Manual for Area-wide Total Pollutant Control (Air Pollution Control Division, 1995). By using these complied functions, the average emission rate can be calculated for average speed of vehicle type i on a link (see (2-1)). Combining the emission rate with the numbers of each vehicle type, the average emission rate of pollutants on a link can be also calculated (see (2-2)).

$$E_i = f\ (\text{average speed of vehicle type } i) \quad (2\text{-}1)$$

where : E_i = emission rate of vehicle type i, $g/\sec$

$$q = V_w \times \frac{1}{3600} \times \frac{1}{1000} \times \sum_i (E_i \times T_i) \quad (2\text{-}2)$$

where :

q = average emission rate, $m\ell/(m \cdot s)$

V_w = transformation factor, $m\ell/g$) ,
in case of NO_X 522.6 $m\ell/g$ (20℃, 1atm)

T_i = trafic volume of vehicle type i , cars/hour

2.4.3 Meteorological model

In the meteorological model, average weather condition is set by average frequency of wind direction, average wind speed, and average classification of atmospheric stability.

The 16th wind direction and 7th speed classification were chosen as the standard values for wind direction and speed classification were used in the prototype system. For the classification of atmospheric stability, Pasquill stability classification that is a representative classification of atmospheric stability was useed in this study (Pasquill, 1976).

2.4.4 Dispersion model

The average emission rate of pollutants calculated from the emission model are then used to determine the concentrations of air pollutants in the dispersion model.

In the dispersion model, dispersion patterns are simulated by the parameters of the average atmospheric stability. In case of wind speed over 1 m/s, "plume" model (see (2-3)) is applied. In case of wind speed below 1 m/s, "puff" model (see (2-4)) is applied as the dispersion function.

The concentration, c, at receptor position (x, y, z) for substances emitted at (0,0,h) is given in (2-3) and (2-4). The receptor height (z) is assumed to be at 1.5 meters corresponding to the height of human' head. The height (h) of emission sources is assumed to be the sum of the height of each link and the average half height of fleets.

$$C(x,y,z;h) = \frac{10^6 q}{2\pi \cdot \sigma_y \sigma_z} \cdot \exp\left[-\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \left\{\exp\left[-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h}{\sigma_z}\right)^2\right]\right\} \quad (2\text{-}3)$$

where :

$C(x,y,z;h)$ = concentration by plume model

q = average emission rate, mℓ/($m \cdot$ sec)

u = mean speed, m/sec

σ_y , σ_z = standard deviation of concentration distribution in the cross-plume and vertical directions, meters. They are a function of atmospheric stability

$$C(x,y,z;h) = \frac{10^6 q}{(2\pi)^{\frac{3}{2}} \cdot \sigma_x \sigma_y \sigma_z} \cdot \exp\left[-\frac{(x-ut)^2}{2\sigma_x^2} - \left(\frac{y}{\sigma_y}\right)^2\right] \cdot \left\{\exp\left[-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h}{\sigma_z}\right)^2\right]\right\} \quad (2\text{-}4)$$

where :

$C(x,y,z;h)$ = concentration by puff model

σ_x = σ_y = $\alpha \cdot t$

σ_z = $\gamma \cdot t$

α = 0.3, γ = 0.18(day), 0.09(night)

The average concentration is then obtained by summing all concentrations dispersed from each link and weighting each one according to its frequency for the particular wind direction, wind speed class and atmospheric stability class. The equation for calculating average concentration is described as (2-5).

$$\overline{C} = \sum_{\theta=1}^{16} \sum_{N=1}^{7} \sum_{S=1}^{6} F(\theta,N,S) \cdot C(\theta,N,S) \quad (2\text{-}5)$$

where :

$\overline{C}$ = average concentration

$F(\theta,N,S)$ = normalizing frequency during period of interest for wind direction interval θ, wind speed class N, and stability class S. There are a total of sixteen wind directions, seven wind speeds, and six stability classes.

$C(\theta,N,S)$ = concentration according to conditions

$$[NO_2] = [NO_X] \cdot \left[1 - \frac{\alpha}{1+\beta}\{\exp(-Kt) + \beta\}\right] \quad (2\text{-}6)$$

where :

$[NO_2]$ = the concentration of NO_2, ppm

$[NO_X]$ = the concentration of NO_X, ppm

α = 0.9

β = 0.3

K = $0.208 \cdot u \cdot [O_3]$

u = wind speed, m/s

$[O_3]$ = the concentration of ozone, ppm

t = time, second

In this study, NO_2 is selected as a representative pollutant because NO_2 is one of the pollutants highly related with road traffic-related environment. In case of NO_2 pollution, NO_X is emitted from vehicles at initial stage(most of

NO_X is NO). NO_X is converted into NO_2 by the interaction with O_3 in the atmosphere. NO_2 is the stable state of NO_X. For this reason, the concentration of NO_2 is focused for the evaluation of air pollution levels in this study. The numerical formula of conversion applied for calculating the concentration of NO_2 in this study is shown in (2-6).

3. APPLICATION OF THE PROPOSED SYSTEM TO THE URBAN AREAS

3.1 Overview of the case study area

As a preliminary stage in developing the prototype system, the metropolitan area of Cairo was selected as a case study among metropolitan areas of developing countries for many reasons. The metropolitan area of Cairo has a considerable growth in the number of motorized vehicles and the government of Egypt considers traffic-related air pollution as an urgent problem deserving high priority for action. Furthermore, traffic surveys have already been conducted by JICA (Japan International Cooperation Agency) for transportation projects and therefore traffic data is readily available. In view of these factors circumstances, the metropolitan area of Cairo was selected as a case study for developing the prototype system.

In the metropolitan area of Cairo, The population in 1986 was 8.63 millions and the population in 2010 is predicted to be 12.97 millions. The number of motorized vehicles in 1987 was 486,400, but recently it shows a 7% increase per year. The emission of black smoke from ill-maintained vehicles causes the main air pollution problems. In addition, the amount of exhaust gas at peak time, worsens air pollution more seriously due to speed reductions by traffic jams.

3.2 Simple survey of air pollution

Monitoring data is needed to estimate a current situation of pollution and provide verification of the simulation model. The number of stations constantly monitoring air pollution is limited for the metropolitan area of Cairo. This makes it difficult to obtain the information on the real situation of air pollution. In this study, a survey of NO_X, NO_2, SO_2 and SPM, was conducted by the simple survey method so that the verification of the simulation model could be made.

The concentrations of air pollution were monitored by the simple survey method over a period of three days in autumn (October) in 1997. The concentrations of NO_X, NO_2 and SO_2 were monitored at thirty-one locations. 4 points were surveyed for SPM.

3.3 Data for the simulation model

For applying the prototype system to the study area of the metropolitan Cairo, the required data were collected and processed in this study. Meteorological data was obtained from Weather Bureaus of Cairo. The O-D (Origin-Destination) table of trip distribution in 1997 and 2005 was based on the data which had been surveyed by the city of Cairo and JICA for "Greater Cairo region transportation master plan study in the Arab Republic of Egypt" in 1989.

For estimating traffic-related air pollution in 2005, the predicted number of vehicles and the planning population of the metropolitan area of Cairo were taken into consideration.

Since there were no data on current vehicle emission factors for NO_X in the study area, data of unregulated emissions period in Japan (1973) replaced them, taking vehicle conditions in Cairo into account.

The transportation network and land-use data were newly digitized for this study. Figure 4 shows the transportation network data and land use data of the metropolitan areas of Cairo.

3.4 Validity test of the simulation model

For verifying the reproducibility of the traffic-related air pollution model, NO_2 is selected because NO_2 is one of the pollutants highly related with road traffic-related environment. For the validity test, the simple survey data of NO_2 were used. Table 1 shows the comparison of NO_2 concentration between the values monitored by the simple survey method and the values estimated by the simulation model. Considering the fact that the simple survey was made over only three days, the result of correlation test is relatively good and is thought to be sufficient for testing the relative effectiveness of the trial strategies for a prototype system.

Table 1 Validity test of the simulation model

Air Pollutant	Number of Samples	Regression form	Correlation coefficient
NO_2	31	Simulated value = 0.545 * Monitored value + 39.84	0.694

3.5 Analysis of present and future traffic-related air pollution situations

Information produced by the proposed system is displayed in the form of computer-drawn maps. Figure 5 shows the map of present annual average distribution of NO_2 . The total emissions of present condition (in 1997) in the study area are also described in the Case 1 of Table 2.

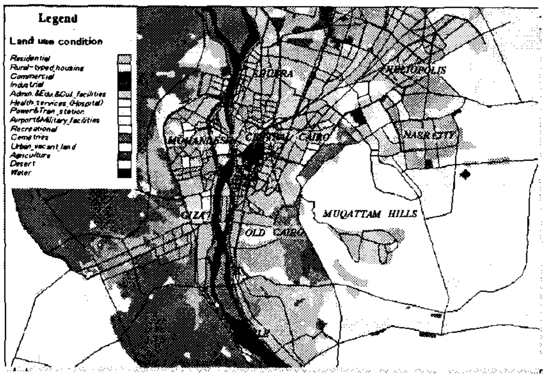

Figure 4 Transport network and land use data of the metropolitan areas of Cairo

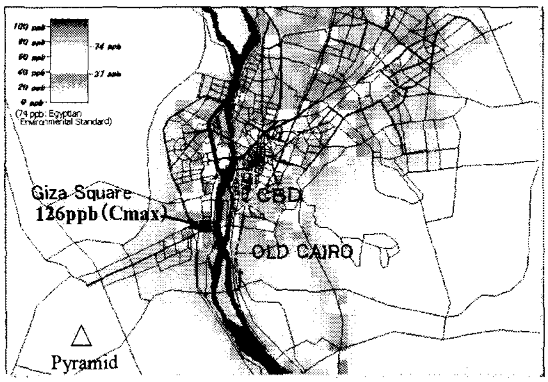

Figure 5 Simulated annual average distribution of NO_2 concentration (1997 present)

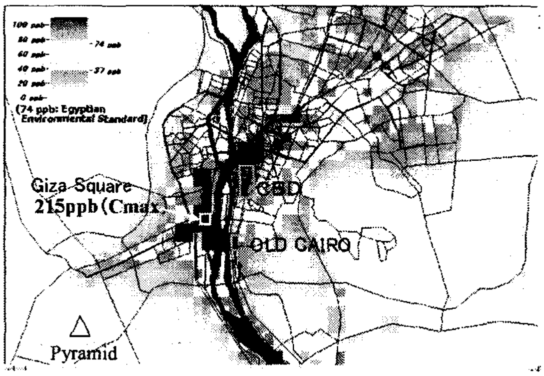

Figure 6 Simulated annual average distribution of NO_2 concentration (2005 assuming no actions)

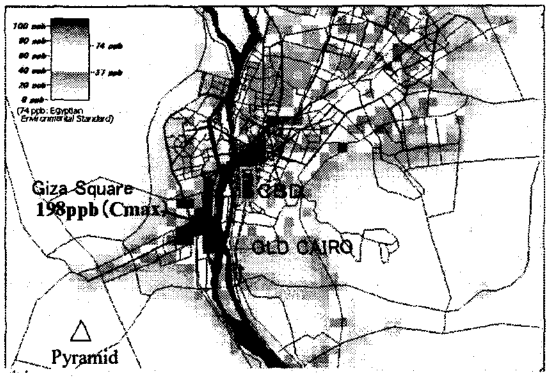

Figure 7 Simulated annual average distribution of NO_2 concentration (2005, construction of 3^{rd} subway system)

While Figure 6 shows the forecasts of annual average distribution and the Case 2 of Table 2 describes total emissions in 2005, assuming that no action are taken for the environment. From the simulated results in 2005, most of central areas of Cairo and Giza and trunk roads will suffer from serious pollution. Some areas are estimated to have the level of NO_2 above 200ppb. The main reason for the results of serious air pollution lies with the problems caused by ill maintained vehicles and heavy road traffic. Following the data surveyed by the university of Cairo, the 66% of registered vehicles are over 10 years old. In metropolitan area of Cairo, the areas of roads are very small and the share of railway system among total trip is also very low. These factors will certainly cause the heavy road traffic and traffic jam in the future. Besides improving them, more comprehensive strategies for the entire areas are also indispensable for solving such serious air pollution.

3.6 Potential strategy analysis in the developed prototype system

From the field survey in the metropolitan area of Cairo, three sets of potential strategies from the database were investigated in this study. The first set of simulations analyzes the effect that improvements in the transit system have an air quality. The second set investigates a policy that would control automobile accessibility to specified areas of the city, and the third set analyzes the effect that reducing vehicle emission rates has on air quality. As concretely investigated examples of three sets, the construction of 3^{rd} subway system, inflow regulation into the CBD (Central Business Districts), and emission control were simulated in this study. By analyzing the impact of several policy strategies within a consistent framework, it should be possible to draw conclusions about the relative efficiency of each strategy in improving air quality level. The analysis results of these three examples are given below.

1) In case of the construction of 3^{rd} subway system

As one example of the simulation results, Figure 6 shows the case in which 3^{rd} subway

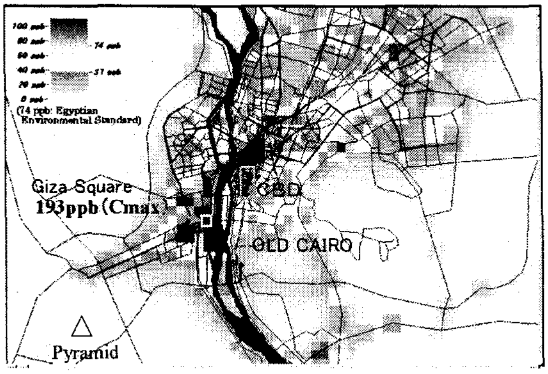

Figure 8 Simulated annual average distribution of NO_2 concentration (2005, inflow regulation into the CBD)

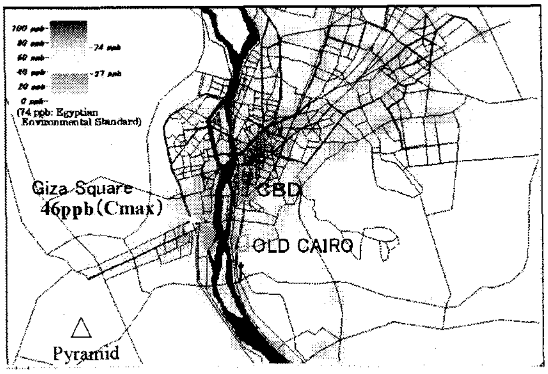

Figure 9 Simulated annual average distribution of NO_2 concentration (2005, controlled by the EPA emission regulations)

that had been already planned was assumed to be completed in addition to the existing two subway systems (in 2005).

When it is operated, the concentration of NO_2 is spatially distributed as shown in Figure 7 and total emissions of NO_X are shown in the Case 3 of Table 2. In this case, the annual average concentration of NO_2 is reduced about 3ppb in the central areas and total emissions of NO_X are reduced by about 554 tons/year (about -2.0%), as compared with "taking no action". In this case, the level of transit service would also be improved by subway system extension. However, such improvement effect was not taken into consideration for the evaluation of trial strategies. The improvement effect of air quality was mainly focused in this study.

2) In case of inflow regulation into the CBD

As an another example of the simulation results, Figure 8 shows the case in which inflow regulation into the CBD is implemented in the CBD of Cairo and Giza (in 2005). When it is implemented, the concentration of NO_2 is spatially distributed as shown in Figure 8 and total emissions of NO_X are described in the Case 4 of Table 2. In this case, the annual average concentration of NO_2 is reduced by about 5 ppb in the central areas and total emissions of NO_X are reduced by about 422 tons/year (about -1.6%).

However, this traffic inflow regulation into the CBD will certainly cause the travel time increase of the zones adjacent to the CBD. The increase in travel time reflects the increase in vehicular traffic in adjacent zones caused by trips that are diverted around the restricted area. In view of this, air quality improvement of the CBD areas is greater with inflow regulation, but on the other hand, the air quality in adjacent zones is somewhat degraded. Comparing it with the subway extension case, the air quality of CBD areas is more improved, but total emissions are less improved. Perhaps the most important point made by the policy of inflow regulation is that localized transportation controls may produce air quality improvements wherever they are applied but reduce air quality levels in adjacent zones. Because localized transportation controls shift air quality problems from one area to another, the net improvements of such policies should be analyzed carefully.

3) In case of emission control

As another example of the simulation results, Figure 9 and Case 5 of Table 2 show the case in which the emission is controlled, following the EPA (Environment Protection Agency) US emission regulations (assumed to be controlled from 2005).

In this case, as the improvement of emission volume, the concentration of NO_2 is reduced in all areas and total emissions of NO_X are reduced by about 20941 tons/year (about -77%). In the central areas, about 20ppb of the annual average concentration of NO_2 are reduced.

These simulation results indicate that the impact on air quality of emission controls is dramatic. The concentration of NO_2 and total emissions of NO_X are shown in Figure 9 and in the Case 5 of Table 2 respectively.

According to these simulated results based on the spatial distribution and total emissions of the air pollutant, it is clear that a strategy of implementing emission controls is a high priority action in the metropolitan area of Cairo.

However, measuring the effectiveness of these air quality improvement strategies for reducing concentration and total emissions is only half of the task of evaluating strategies because the costs of implementing the strategies vary widely. In the developed prototype system, the emissions of air pollutants and the spatial distribution were mainly focused on for the evaluation of trial strategies. For more generalized comparison and evaluation of trail solutions, generalized cost-benefit analysis of environmental changes is indispensable. However, such analysis process is not yet established in the developed prototype system. Estimating the costs and benefits of some strategies is extremely difficult and, in some cases, it is impossible to formulate. Especially in case of air quality, obtaining appropriate quantitative estimates of willingness to pay for clean air is a task of great difficulty because private markets for clean air do not exist. As a further study, the developed system will be updated to be suitable to more generalized evaluation for road traffic-related environment problems, including generalized cost-benefit analysis of air pollution improvement strategies.

Table 2 Total emissions of simulation cases

Simulation cases	Emissions of NO_X (ton/year)
Case1: 1997 Present	15,979
Case2: 2005 Assuming no actions	27,068
Case3: 2005, Construction of 3rd subway system	26,514
Case4: 2005, Inflow Regulation into the CBD	26,646
Case5: 2005, Controlled by the EPA emission regulations	6,127

4. CONCLUSIONS

In this study, the GIS-supported evaluation system was established for the evaluation of potential strategies to cope with traffic-related environment problems. As a preliminary stage in developing the prototype system, the metropolitan area of Cairo was chosen as a pilot study to test the applicability of the system. By using the developed prototype system, the situations of air pollution were efficiently simulated and graphically displayed on real locations under the assumption of the implementation of potential strategies. It is best suited to simulate and evaluate any strategies before establishing a final scheme within GIS-supported environment. It can also be more useful as a policy analysis tool in situations where it might be difficult to implement policies or where it is expensive to experiment with real system.

The spatial distributions of air pollution concentrations, simulated in the developed system, are of particular importance when graphically presenting environment impact to decision makers and effectively communicating with affected residents or public representative during any public consultation process. The study findings can also be helpful in making more reasonable decision by reducing human exposure to pollutants decreasing risks to health and environment. In view of these facts, the developed system holds good for wider applications in traffic-related environment problems.

Although there are many aspects that need to be updated for more generalized evaluation, these results confirm the system's effectiveness and support the further development of the system as a tool for environment problems.

ACKNOWLEDGEMENTS

This study is a part of the project of "Cooperation Plan for Traffic-related Pollution in the Developing Countries" that has been undertaken by the Ministry of Transportation of Japan. The author would like to extend his sincere gratitude for getting invaluable ideas and comments to all members of the committee for the project.

The author also wishes to thank two anonymous referees for their useful comments on earlier drafts of this paper. The author, however, are solely responsible for any remaining shortcomings.

REFERENCES

1. WHO (1992) Our Plant Our Health : Report of the WHO Commission on Health and Environment, World Health Organization, Genova.
2. WHO/UNEP (1992), Urban air pollution in megacities of the world, Blackwell, Oxford.
3. Air Pollution Control Division (1995), Nitrogen Oxides Concentration Operation Manual for Area-wide Total Pollutant Control, Japan Environmental Agency (in Japanese).
4. Japan Transport Cooperation Association (1995), Report of Urban Transport-related Countermeasure Study (in Japanese).
5. Pasquill, F.(1976) Atmospheric Diffusion, Ellis Horwood Book Co., London