การประยุกต์ใช้ระบบสารสนเทศภูมิศาสตร์สำหรับวิเคราะห์มลพิษทางอากาศจากการจราจรในเขตเมือง

Applications of GIS for Analyzing Air Pollution from Urban Road Traffic

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บทคัดย่อ

มลพิษอากาศที่เกิดจากการจราจรเป็นปัญหาสิ่งแวดล้อมที่มีความสำคัญมากโดยเฉพาะในเมืองใหญ่ ๆ เช่น กรุงเทพมหานคร เชียงใหม่ สงขลา ขอนแก่น เป็นต้น การปล่อยออกมาของมลพิษอากาศของรถแต่ละคันขึ้นอยู่กับปัจจัยหลายอย่างและการแพร่กระจายของมลพิษอากาศที่ถูกปล่อยออกมานั้นก็มีความซับซ้อน ดังนั้นการทำนายหรือประมาณค่าระดับมลพิษอากาศที่เกิดขึ้นจากการจราจรจึงกระทำได้ค่อนข้างลำบาก แต่อย่างไรก็ตาม นักวิจัยก็สามารถที่จะจำลองลักษณะการเกิดและพฤติกรรมการแพร่กระจายของมลพิษอากาศได้โดยใช้แบบจำลองคณิตศาสตร์ ซึ่งสามารถนำไปใช้เป็นเครื่องมือในการทำนายมลพิษอากาศที่จะเกิดขึ้นเมื่อมีการจัดการหรือก่อสร้างโครงการด้านการจราจรและขนส่งได้ ในขณะที่ระบบสารสนเทศภูมิศาสตร์ (Geographic Information System, GIS) เป็นระบบที่มีความสามารถในการจัดเก็บ สืบค้นและวิเคราะห์ข้อมูล และสามารถแสดงผลเชิงพื้นที่ได้เป็นอย่างดี ดังนั้น การประยุกต์ใช้ GIS ร่วมกับแบบจำลองคณิตศาสตร์ทางด้านมลพิษอากาศจะช่วยให้นักวางแผนการจราจรและขนส่งสามารถที่จะประเมินโครงการ/แผนงานที่เสนอได้อย่างมีประสิทธิภาพ บทความนี้จึงได้อธิบายถึงลักษณะการพัฒนาเครื่องมือเพื่อช่วยในการวิเคราะห์ปัญหามลพิษอากาศที่เกิดจากการจราจร ทั้งจากต่างประเทศและในประเทศไทยเพื่อเป็นแนวทางสำหรับการพัฒนางานวิจัยทางด้านนี้ต่อไป

Abstract

Traffic air pollution is an important environmental pollution, particularly in major cities such as Bangkok, Chiang Mai, Songkla, Khon Kaen, etc. The air pollutant emission of each vehicle depends on several parameters and its dispersion is quite complicated. Therefore, the prediction or estimation of traffic air pollutants is absolutely difficult. However, researchers can simulate the generation and dispersing behavior of pollutants by mathematical models, which can be used as tools for predicting air pollution when implementing the proposed traffic and transportation plans. The Geographic Information System (GIS) can store, receive queries, and analyze data, and display spatial results very well. Therefore, the application of GIS and mathematical air pollution models will help traffic and transport planners evaluate the proposed projects/plans efficiently. This paper describes the research in development of such tools for analyzing air pollution from road traffic in urban areas both from abroad and in Thailand. These can be used as guidelines for further research.

คำสำคัญ: มลพิษอากาศ การจราจรทางถนน ระบบสารสนเทศภูมิศาสตร์

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Introduction

Road traffic is a major source of air pollution in urban areas. It is largely responsible for CO, HC, NO_X and particles emissions in urban road networks. It leads to environmental problems especially from the increase of automobiles that are the major mode of urban transport. Therefore, the capability of a model for air pollution prediction from road traffic is significant. There are several factors affecting emission generation from road traffic. For example, vehicle characteristics (type of engine, the energy efficiency of the vehicle, vehicle age), weather conditions and driving behavior (speed, acceleration and idling). In transportation planning and policy analysis, a mathematical model is used for estimating environmental impact such as air quality.

A Geographic Information System (GIS) is a tool for identifying and assessing the impact of transportation on the environment (Miller and Shaw, 2001). In addition, GIS supports spatial analysis and improves the model's performance with respect to prediction that allows the use of spatial coordinates to describe the structure of urban areas, road networks, and pollutant distribution in the atmosphere (Gualtieri and Tartaglia, 1998). Thus, GIS can be used as a decision support system tool for traffic engineers, urban planners and other decision-makers.

There are several researches that have focused on the assessment of the effect of air pollution. Gualtieri and Tartaglia (1998) developed a comprehensive model for the evaluation of air pollution caused by road traffic in urban areas to help the decision making of local administrators. Jeboji and Sturm (1999) integrated existing emission calculation software with a graphical user interface to estimate traffic air pollution. Jenson et al (2001) developed a model that combined GIS and the Danish Operational Street Pollution Model, for population exposure to traffic air pollution in order to improve assessment of health impacts and in support of risk management. Lin Der and Lin Chang (2002) integrated a GIS model for evaluation of transport-related air pollution situations in an urban area. The key findings revealed that the integrated system can provide decision-makers with up-to-date emission information and provide additional visualization and analysis capability. Tippichai et al (2003) developed a computer-based program to predict emission from road traffic in urban areas and linked it to a GIS for identifying the risk area. This paper describes the methodology of development of GIS tools for air quality analysis by researchers in several countries and compares them illustratively.

Air Quality Models

The mathematical models related to traffic air pollution mostly consist of three major sub-models: Traffic model, Emission model, and Dispersion model. The traffic model is used for simulation or prediction of traffic conditions (e.g. traffic flow, traffic composition, speed, etc.) on each road segment. The changing of traffic conditions that is mainly a result of the implementation of proposed transportation projects can be estimated by the traffic model. However, for air quality prediction of the present traffic situation, several researchers used collected traffic data. A comparison of the components of models is shown in Table 1.

Most exhaust emission models use emission coefficients (emission factor) to estimate vehicle emission as shown in Table 1. The emissions of the vehicle fleet were calculated, based on the emission model coefficients, traffic volume, and road segment length (Jensen et al, 2001; Lin et al, 2002). Table 2 shows CO emission coefficients for nine types of vehicles at different speed ranges, employed in the emission estimation. The nine categories of vehicle are: private light duty gasoline vehicles (PLDGV), business light duty gasoline vehicles (BLDGV), light duty gasoline trucks (LDGT), light duty diesel trucks (LDDT), heavy duty diesel trucks (HDDT), heavy duty gasoline vehicles (HDGV), buses (BUS), 2-stroke motorcycles (MC2), and 4-stroke motor cycles (MC4) (Lin Der and Lin Chang, 2002).

The air quality model also includes the calculation of emission dispersion. Reboji and Sturm (1999) calculated emission distribution based on a simple Gauss solution for linear sources. They noted that the use of a Gauss linear source model is based on the principle of overlaying, which means that the concentrations of emitted substances at the receiving point equals the sum of dispersions of all infinitesimal point sources which together build the linear sources. The ambient hourly concentration level of each pollutant depends on inputs of street configurations and hourly inputs of traffic, meteorological parameters, and urban background concentrations. Another method is the street canyon, used for calculating the local contribution (micro-scale) within urban sites where a road section is surrounded by tall buildings on each side (Gualtieri and Tartaglia, 1998). Moreover, the physical and chemical processes greatly affect the concentrations, and pollution levels can be computed as the sum of the direct contribution from traffic and the contribution from the wind generated recirculating of air pollution inside the street environment (Jensen et al, 2001).

GIS-based Tool Developments

Gualtieri and Tartaglia (1998) developed the GIS model as shown in Figure 1. The model has a three-level structure, including the whole database, a number of mathematical models, and the subsequent results in terms of thematic mapping. The GIS database is provided by road network territorial data, traffic demand characteristics, driving cycles and fleet composition, and a number of data defining an adequate meteoclimatic scenario. The street configuration data are static data that describe the physical environment around the receptor points. Examples of street configuration data are street orientation, street width, building heights in wind sector, etc. The graphical data (also called spatial data) is stored in suitable formats: geocode addresses as points, buildings as polygons, and streets as polylines as shown in Figure 2.

The calculation of emission and dispersion can be categorized into two alternatives. The first alternative is programming of the equations of mathematical models both of emission and dispersion models directly in GIS software using a special macro or programming language, so-called GIS-centric application (ArcView using Avenue or MapInfo using Mapbasic) (Rebolj and Sturm, 1999). The second alternative is the development of the existing mathe matical model independently separated from GIS as described in Rebolj and Sturn (1999) that uses an existing batch program developed in FORTRAN. This method needs an interface module to allow the communication between GIS and mathematical model for easy to use.

GIS-based Mapping Results

Most GIS packages have many methods to visualise and display data contained in a map layer quickly and efficiently. They are capable of zooming in and out on the map layer, highlighting by selection, classifying the selected map features in the map layer according to certain criteria and then displaying those map features in different coded colours. All associated attributes of each map feature can be easily retrieved and displayed by simply clicking on each object. Traffic volumes, speeds, environmental sensitivity indices, and others can be nicely illustrated on a monitor screen with different colours and symbolic schemes according to the magnitude of the corresponding values as shown in Figure 3. In addition, a road network map layer can be superimposed on top of the colour aerial photograph with appropriate resolution as shown in Figure 4. This ability can provide an excellent way of understanding and interpreting the nature and scope of outcomes derived from transportation planning and analysis, as well as communicating between traffic and transportation engineers, urban planners, local government officials, decision makers, and affected residents.

Conclusion

Traffic air pollution has become a major concern to urban planners, developers and health officials. It is necessary to examine pollutant emission quantities and their spatial distributions frequently and also to evaluate the variation of these situation traffic management policies or traffic conditions. Hence, there are growing tools that can provide an easy access to obtain up-to-date mobile source emissions information. The integrated model which combines traffic flow prediction, emission model, dispersion model and databases in a GIS framework should be a suitable tool. It can be concluded that the visualization and analytical features of GIS provide more information and convenience to users. It also makes the model more efficient and flexible.

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Table 1 Comparison of the components of 5 GIS models

Authors	Traffic Model	Emission Model	Dispersion Model	Developing Tool
Gualtieri et al (1998)	- O-D matrix - Road network - Equilibrium assignment	- Emission factor	- Gaussian - Street canyon	- MapInfo
Rebolj et al (1999)	- Existing traffic data	- External batch program by FORTRAN	- External batch program by FORTRAN	- Visual Basic - MapObjects
Jensen et al (2001)	- Existing traffic data	- Emission factor	- CALINE4	- ArcView
Lin et al (2002)	- Existing traffic data	- Emission factor	- Operational street pollution model (OSPM)	- ArcView
Tippichai et al (2003)	- Existing traffic data	- Running speed model - TSC model - TRRL model	- Ongoing research	- ArcView

Table 2 Emission coefficients of CO

Speed (km/hr)	PLDGV	BLDGV	LDGT	LDDT	HDDT	HDGV	BUS	MC2	MC4
5	95.24	72.82	84.60	4.93	23.47	19.10	27.01	35.69	22.86
10	52.27	40.46	43.37	3.85	18.34	14.92	21.10	19.52	12.47
15	35.47	29.12	28.45	3.06	14.58	11.86	16.77	12.77	8.14
20	27.32	23.57	21.16	2.48	11.79	9.59	13.57	9.46	6.01
25	22.73	20.34	16.95	2.04	9.71	7.90	11.17	7.60	4.83
30	19.79	18.22	14.21	1.71	8.14	6.62	9.36	6.43	4.06
40	15.17	13.33	11.69	1.26	6.02	4.90	6.93	4.93	3.10
50	12.04	10.04	10.05	1.00	4.78	3.89	5.50	3.93	2.47
60	9.90	7.85	8.95	0.86	4.07	3.31	4.69	3.25	2.03
70	8.59	6.36	8.28	0.78	3.72	3.03	4.28	2.84	1.77
80	8.03	5.56	7.99	0.77	3.65	2.97	4.20	2.67	1.66
90	9.52	6.21	9.68	0.81	3.84	3.12	4.42	3.25	2.02
100	19.57	10.58	21.02	0.91	4.33	3.53	4.99	7.16	4.00

(Source: Lin Der and Lin Chang (2002), pp. 13)

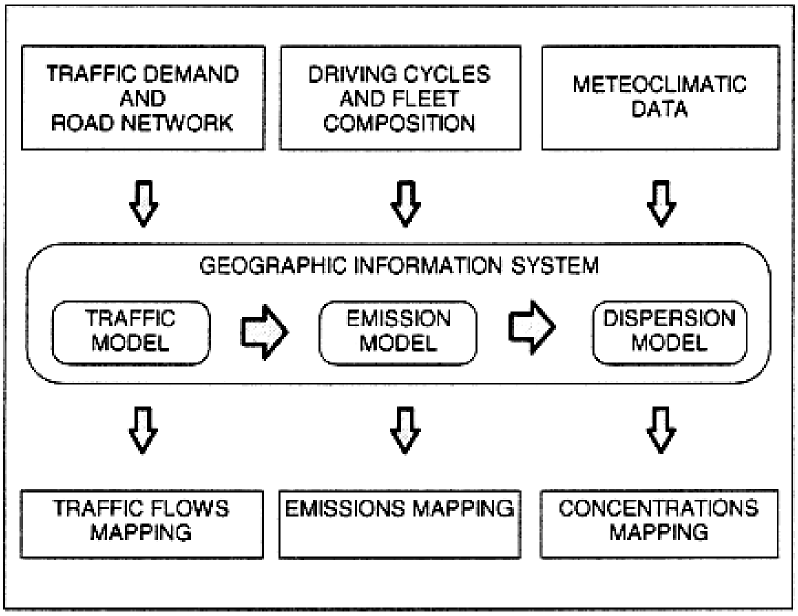


Figure 1 The GIS structure

(Source: Gualtieri and Tartaglia (1998), pp. 330)

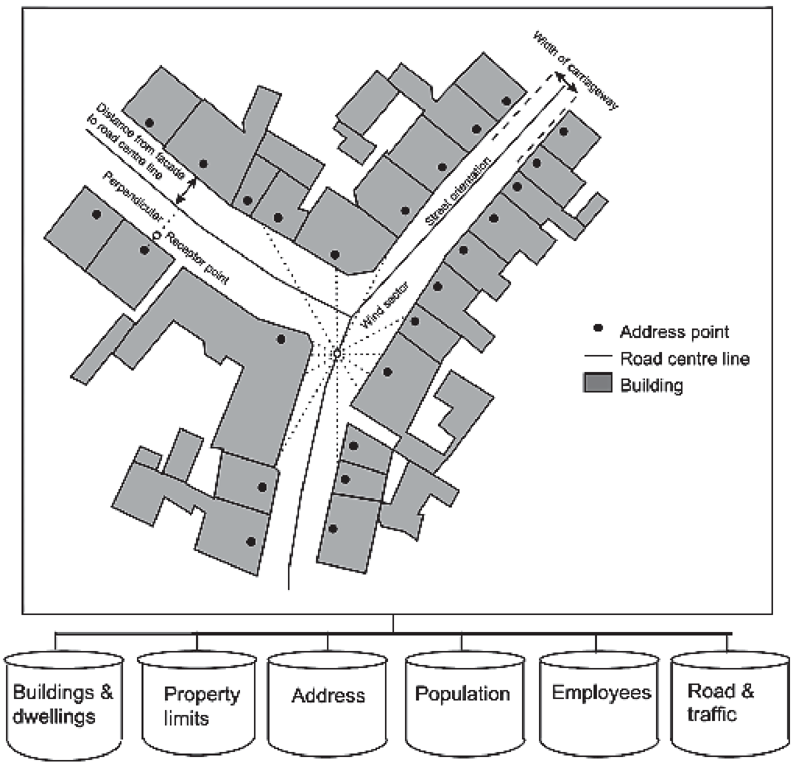
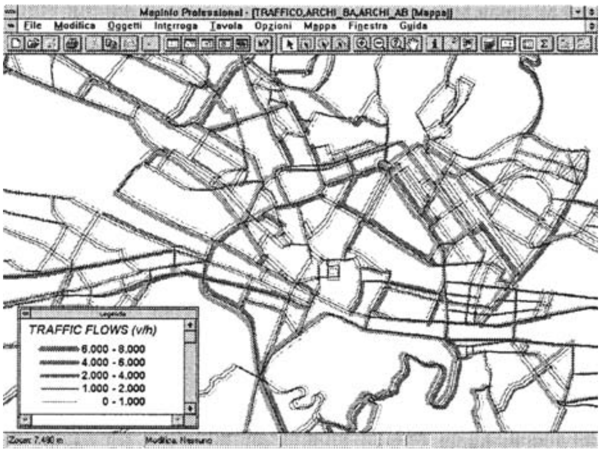
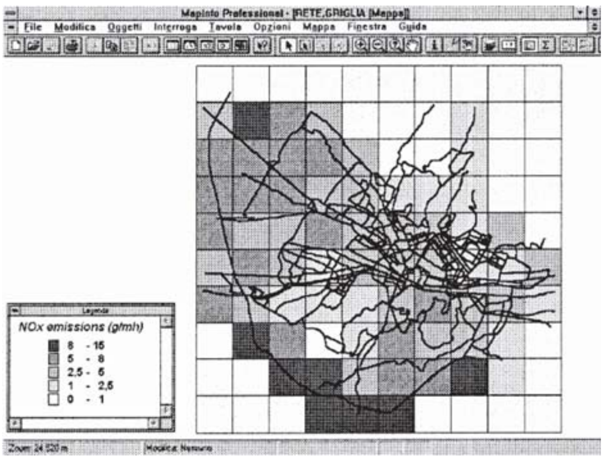


Figure 2 Street configuration parameters and examples of database groups

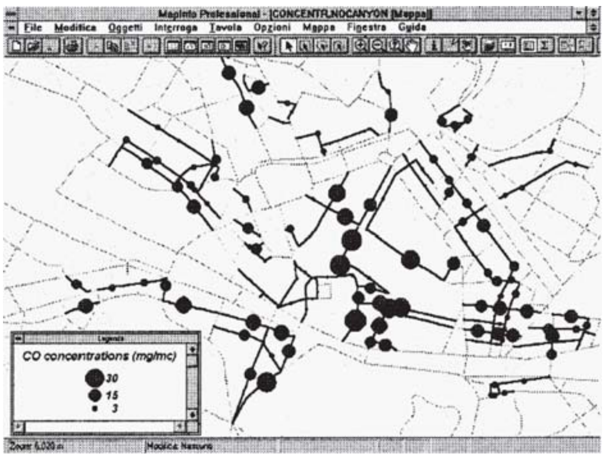
(Source: Adapted from Jensen (2001), pp. 232 and 233)



(a) Mapping of traffic flows



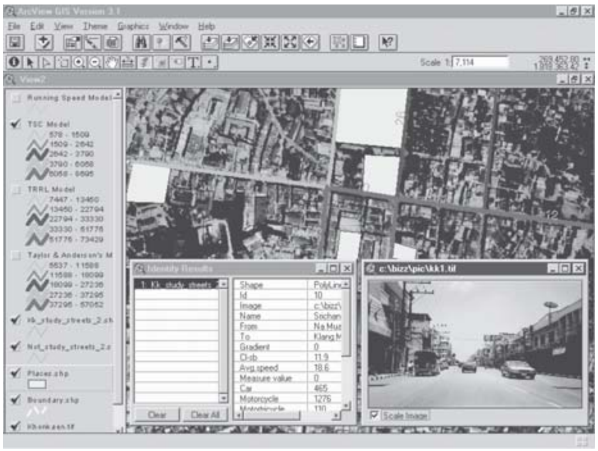
(b) Mapping of NOx emission in a 1.5 km wide grid representation



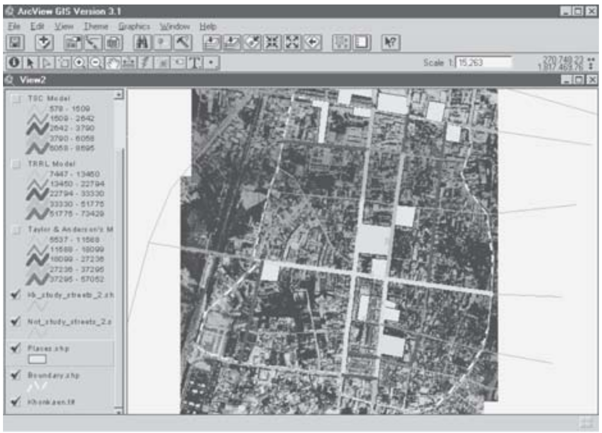
(c) Mapping of CO concentrations within all canyon links of road network

Figure 3. Example GIS mapping over the city of Firenze to represent capabilities

(Source: Gualtieri and Tartaglia (1998), pp. 333-334)



(a) Showing more information with link details and road photo



(b) Prioritizing the CO emission and identifying the risk area

Figure 4 The Khon Kaen road network superimposed on an aerial photograph

(Source: Tippichai et al (2003))