Presented at 8th World Conference on Transport Research, Antwerp, 1998.7.

Topic code: F4
No. 238
Revised version

KNOWLEDGE AND EXPERIENCE-BASED EXPERT SYSTEM FOR TRANSPORT-RELATED AIR POLLUTION IN DEVELOPING COUNTRIES

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benefits could also occur in the form of reducing global climate change and traffic accidents or congestion.

Considering the experience of developed countries, if initiation of some measures has started earlier, the improvement of traffic-related environmental problems is relatively easily achieved and at least, serious air pollution problems can be avoided.

However, most of developing countries are lacking technology, know-how, experience, human resources, facilities for monitoring and inventories of emissions and the financial ability to solve this problem. On the other hand, developed countries have accumulated a great deal of know-how and many experiences concerning traffic-related pollution since 1960's. Various programs for supporting developing countries have been implemented by some developed countries or organizations. In these circumstances, developed countries are expected to play a significant role in the solving environmental problems in developing countries. Also many developing countries have also accumulated considerable knowledge and experiences by themselves.

Traffic problems are caused by the complex combination of geographical and meteorological conditions, traffic-related facilities and customs. Furthermore, many fields such as energy, cars, laws, and economics interact with each other, and that makes it more complex to investigate optimal measures in the studied cities. Therefore, only the comprehensive package including all of these fields can make implementing measures effective.

There is another problem in the application of some technologies in developing countries, there are very limited available data. It makes the application of the standard approaches that use mainly quantitative data difficult.

Considering all this, there is a need for developing an expert system based on the comprehensive knowledge and experience of developed countries. The effective solution of air pollution requires the systematic integration of comprehensive knowledge and experiences. Knowledge and experience-based systems have been explored for reducing the statistical requirements as well as increasing the ability to solve complex problems. In developing the system, computerized tools such as GUI (Graphic User Interface) are also indispensable for effectively handling the required analysis.

Under the circumstances, as a kind of solution to traffic related environmental problems of developing countries, we are trying to establish a "Knowledge and Experience-based Expert System for Transport-related Air Pollution in Developing Megacities". By establishing the proposed system with user-friendly GUI, the proposed system provides a flexible and useful tool for testing the best solution for the city concerned. The system can assist the inexperienced traffic and environmental officers and engineers in developing countries to improve the air pollution problems of their countries.

In this study, the proposed system is applied into the cities of Jakarta in Indonesia, Dalian in China, Cairo in Egypt and Nagoya in Japan as a standard city for testing the potentiality of the system. Especially, the functions of our system through the survey, analysis of problems & causes, and proposal of measures for air pollution problem in Jakarta will be explained in this paper.

2. THE BASIC CONCEPT OF THE PROPOSED SYSTEM

2.1 Overview of the proposed system

2.1.1 The processes of the proposed system

The proposed system is being developed on the model of a medical examination whereby the metropolitan area is regarded as a patient. The system is composed of five steps by analogy with the medical screening process; preliminary survey(interview), field survey(examination), analysis of problems & causes (diagnosis), proposal of measures (prescription) and discussion for implementation(consultation). The queries made by the system are in the form of multiple choice questions or numerical inputs and the system is operated by the user keying through GUI. A simulation model of traffic-related air pollution that is designed to interact with the diagnosis and prescription process is also established. It is used for estimating the future situation and simulating the effects of alternative measures as well as estimating the present distribution of air pollution. The configuration of the total processes of the proposed system is shown in Figure 1.

2.1.2 GUI typed expert system

When designing the proposed system, the fact that the developed system will be used to assist inexperienced engineers and officers in traffic and environmental fields is kept in mind. Considering this, the proposed system is processed by analogy to the medical screening process for easy understanding. The concept of the proposed system is shown in

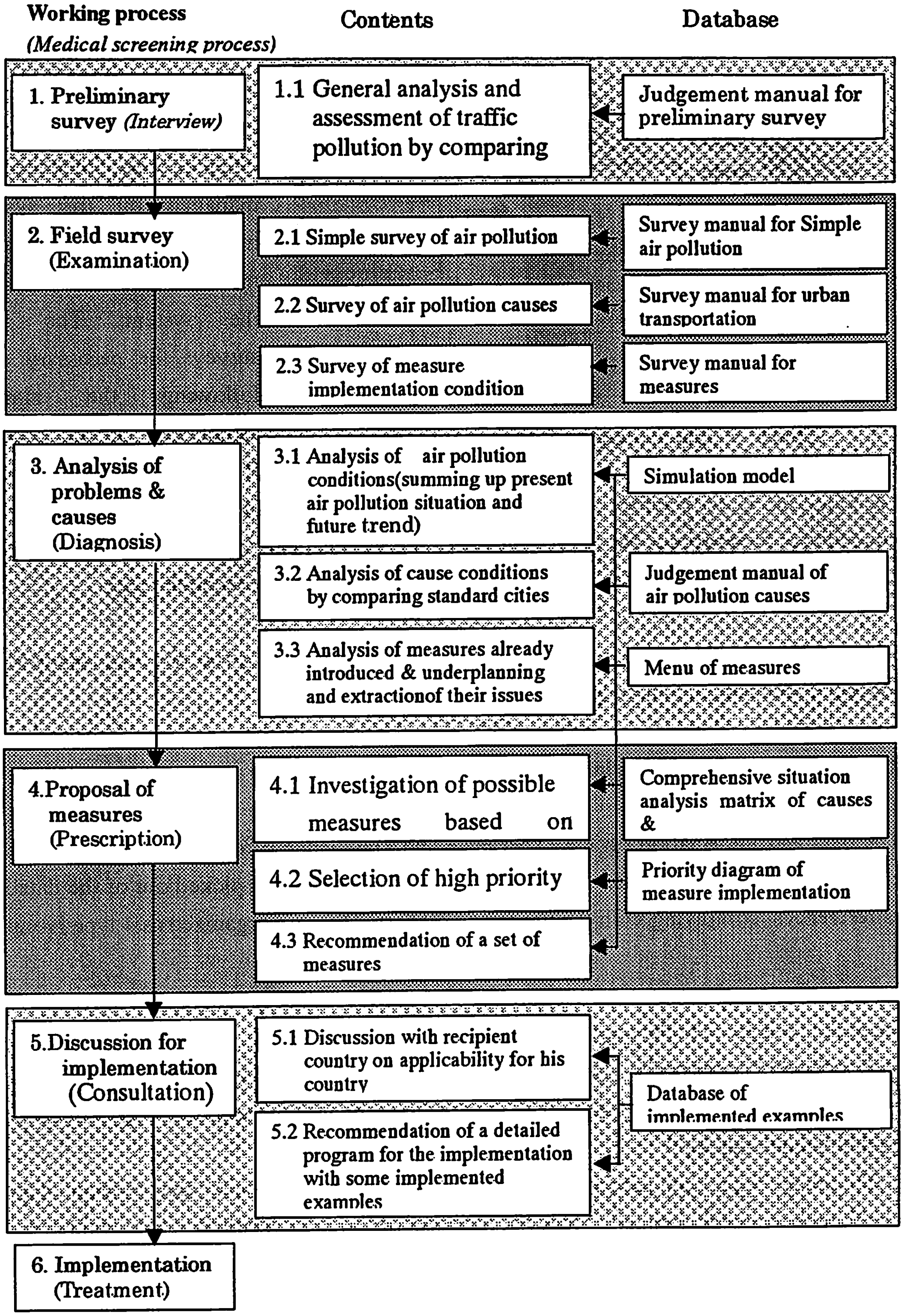


Figure 1 The outline of the total process of the proposed system

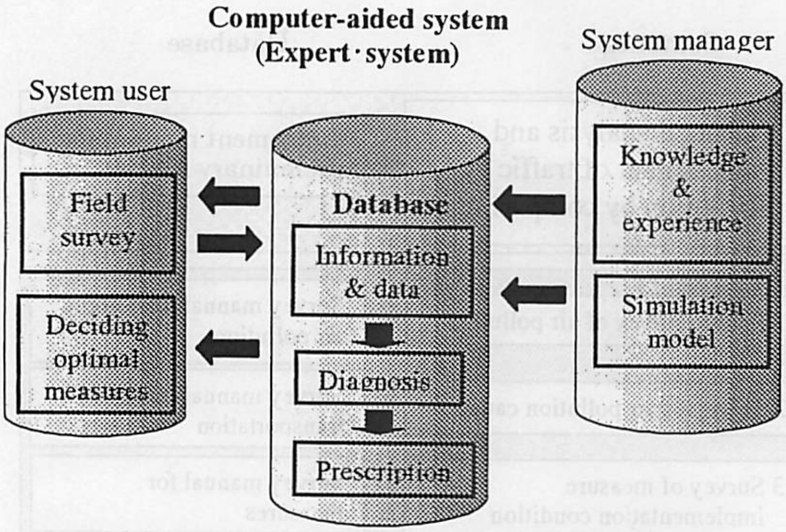


Figure 2 The concept of the proposed

Figure 2. In the system, the experience and knowledge of the cities of developing and developed countries in addition to the standard cities in Japan are saved and managed by the system manager. A simulation model is also established in the system. The user surveys the necessary data following the manual established in the system. By the user keying through GUI(Graphic User Interface), the system is operated and the air pollution condition in the studied city is analyzed. Necessary measures are automatically prescribed by the analysis results. The used data is also saved as database as reference data to other cities.

Such a GUI typed expert system is very effective in handling the required analysis for inexperienced officers and engineers.

2.1.3 Database of traffic-related air pollution

The data and information on the experience and knowledge of developed and developing countries in addition to Japan are saved as a database. They are picked out of the database as references, complying with the necessary request. They are organized as 4 type groups.

a) Manual : It is database of the manual for surveying air pollution condition, causes, and measures. It is used in the step of field survey.

b) Database of assessment criteria : It is the database established by the data of standard cities including Nagoya in Japan. It is used as assessment criteria in the step of analysis of problems and causes.

c) Database of priority diagram for measure implementation and inter-relation diagram between measures and causes : It is the database of the inter-relationship diagram between measures and causes. The inter-relationship diagram is derived from the knowledge obtained from related literature and the various experiences of developing and developed countries. It is used in deciding the necessary measures for solving air pollution causes and implementation priority between necessary measures.

d) Database of existing experiences : It is the database of existing experiences on measure implementation in all over cities. It includes the concrete contents, the effectiveness, the implementing steps of each measure. It is used as references in the consultation process for finding optimal measures in the studied cities. By establishing this database in the proposed system, the system can be also used as lexicon for traffic-related air pollution problems and such a function is very useful to traffic and environmental officers and engineers who does not have sufficient knowledge and experience.

2.2 The investigation process of necessary measures in the proposed system

For explaining the outline of the process for the investigation process of necessary measures in the proposed system, simple symbols are used for efficient explanation in this chapter. Figure 3 shows the investigation process of necessary measures and the process is concretely explained below.

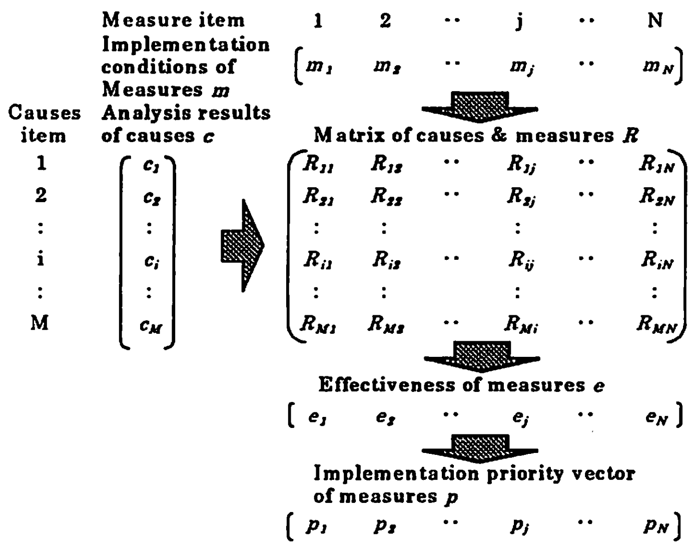


Figure 3 The investigation process of measures to be needed

Comprehensive matrix of causes & measures [*R*]

The matrix shows the inter-relationship a measure *i* is how much effective for solving a cause *j*.

R_{ij} =2 (very effective), 1 (effective), 0 (no direct inter-relationship)

R_{ij} is same values in cities all over the world because it shows common inter-relationship between causes and measures. The value of R_{ij} is obtained from the knowledge and experiences.

(2) The vectors of the evaluated results of causes [*c*] and the evaluated implementation conditions of measures [*m*].

The vector of [*c*] shows the assessed level of each cause item and the vector of [*m*] shows the assessed level of each measure item on implementation condition. The assessed level of each vector is various, depending on the situation of each city. Through the field survey, the related-information and data in the study cities are collected. The collected information and data are assessed by assessment criteria established in the proposed system.

(3) The matrix of effectiveness of measure

By the matrix of causes & measures [*R*], the cause items that are related to a measure are picked up and the effectiveness of a measure is assessed as the summation of the assessed levels of cause items picked up becoming worse. The effective level of a measure is calculated by the function explained below.

$$[e] = [c]^T [R]$$

here, c_i = 0,1,2,3,4 (evaluated according to five ranks (0 to 4) : Rank 0 being excellent and rank 4 being worse).

3. SURVEY AND ANALYSIS PROCESS

In this chapter, the foreword part of the system (e.g., the steps of survey and analysis process) is explained. That is to say, a preliminary survey, field survey and the analysis of problems & causes are described in chapter 3.

3.1 Preliminary survey

In the system of this study, we first establish an outline check-list which composes a set of items to make a diagnosis of the overall condition of transport and environment in the studied city.

Table 1 Examples of the items in preliminary survey

Items	← [For environment] → Good				Bad	unknown
	A	B	C	D	E	
1. Social-economic condition						
① Main function of city		●				
② Level of income				●		
③ Level of motorization			●			
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Since the system has interactive user-interface, input processes are proceeded by input lists with commentaries. One example of typical items is shown in Table 1 for preliminary survey. Based on the these qualitatively evaluated results, the overall understanding of the situation is grasped and it is used for deciding whether the next steps of the proposed system will be carried out or not. If the evaluated overall situation is bad or is becoming worse, the system recommends analyzers to proceed to the next steps with more concrete data for more detail analysis and prescription.

As a preliminary stage in developing a system for the cities of developing countries, Jakarta in Indonesia was selected as one of the case studies. As an example of preliminary survey, the summary of preliminary survey on Jakarta is described in the following sentences.

Jakarta is subject to considerable growth in the number of motorized vehicles, with severe traffic jams. The government of Indonesia considers the air pollution problem as an important issue. However, considering traffic related environmental problems, this city does not have sufficient planning and experience. With the increasing economic activities, traffic related environmental problems can nevertheless be easily predicted to be worsening. Considering these conditions, the system recommends analyzers to proceed to the next steps with more concrete data for more detailed analysis and prescription.

3.2 Field survey

In field survey (examination), transport and environment-related surveys are conducted to collect basic information for situation analysis and the proposal of necessary measures, following the field survey manual established in the proposed system. There are three main parts in field survey: survey for the analysis of air pollution, its causes, and its measures.

Through field surveys, the information and data on traffic related environment problems of Jakarta were collected from interview, and existing documents (BAPEDAL, 1993, Japan Transport Cooperation Association, 1995). Through these transport and environment surveys, the basic information for analysis and proposal of measures were obtained. Users input the obtained information into the system, following the queries in the form of multiple choice questions or numerical inputs through GUI. The main items of field survey are concretely explained as follows.

3.2.1 The condition of air pollution

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, and Lead. For identifying the condition of air pollution, however, air pollution data on six air pollutants explained above are needed. In case of developing countries, there are very limited existing data that were surveyed by the authorities in the city. In this case, new air pollution data are monitored by the simple survey method in the proposed system. A simple method has been provided to facilitate an on-site understanding the extent of air pollution with which measuring concentration of NO_x, NO_2, SO_2 and SPM at some representative sites to supplement existing data. The simplified measuring equipment returned values within 10% of those obtained with well-maintained measuring equipment located in an environmental monitoring station in Japan. So, the simple methods have enough accuracy for understanding the status of air pollution.

Since the simple method is available only for the above four kinds of pollutants, they are used as representative data for air pollution as a whole in the case of the developing countries. In this simple survey, the number of sites will be also still limited. Therefore, only an outline analysis can be made at this stage. These survey data are mainly used for the understanding of the outline and the validity test of a traffic-related simulation model. For estimating the concentration of overall city area or a point in the city, traffic-related air pollution simulation model of which validity is already tested by the simple surveyed data of the studied city is adapted in this study.

3.2.2 The causes of air pollution

To analyze environmental problems, the traffic-related causes must be also surveyed. Traffic related causes are resolved into four primary contributing factors.

Pollution source: The existence of vehicles emitting high concentration gas.
Traffic volume: The increase of total exhaust gas due to the increase of traffic volume.
Traffic flow: The increase of high concentration exhaust gas due to traffic jams.
Miscellaneous: The stationary air pollution sources, unreasonable land-use pattern, etc.

These factors interact with each other or the other factors: stationary sources, natural conditions (geographical and meteorological conditions) and social awareness levels for air pollution problem. Such complicated interaction processes contribute to the symptoms of air pollution as a result. The main items for the situation analysis of the causes are listed in the Table 2 as examples. Based on the information obtained through the checklist, an analysis of the causes is proceeded in the next step (explained in chapter 3.3).

Table 2 Main items for the situation analysis of the causes

1. Pollution source	1.1 Fuel (*Ingredient, Amount of consumption*) 1.2 Vehicle (*Regulation level of emission, Level of maintenance, Age distribution*)
2.Traffic volume	2.1 Individual Transport (*Passenger car, Motor cycle*) 2.2 Public Transport (*Bus, Railway system, Taxi & Pratransit*) 2.3 Freight traffic (*Trucks*) 2.4 Traffic volume control
3. Traffic flow	3.1 Level of road stock 3.2 Traffic management (*Traffic management, Segregation of pedestrian*)
4. Miscellaneous	4.1 Roadside land use (*Roadside land use, Green belt*) 4.2 Monitoring (*Monitoring stations*) ionary pollution source

3.2.3 The measures to be needed

To analyze the situation, we also have to survey the information of the measures being implemented or planned in the studied city. By surveying the measures already introduced or planned and extracting their issues, basic information can be extrapolated for the investigation of measures to be needed.
The measures are grouped into four primary contributing factors.

Control of source: Control of fuel and vehicles emitting high concentration gas.
Control of traffic generation: Improvement of public transportation, control of ownership and inflow control into central city area.
Control of traffic flow: Improvement of road facility and traffic rules.
Social roles: Enforcement of social awareness of air pollution and relocation of urban facilities.

The main items of the measures are listed in the Table 3 as examples.
Based on the information obtained through the checklist, an analysis of measures on implementation is proceeded in the next steps (explained in chapter 3.3).

Table 3 Main items for the situation analysis of the measures

1. Control against pollution source	1.1 Fuel improvement 1.2 Strengthening of emission regulation 1.3 Increase of emission inspection facilities 1.4 Introduction of lower pollution level vehicles
2. Control against traffic volume	2.1 Inflow control into CBD 2.2 Regulation of vehicle ownership 2.3 Improvement of bus service 2.4 Improvement of taxi & paratransit
3. Control against traffic flow	3.1 Improvement of road facilities 3.2 Enforcement of traffic rules
4. Improvement of social roles	4.1 Improvement of social awareness 4.2 Relocation of urban facilities 4.3 Establishment of monitoring systems

3.3 Analysis of problems & causes

In order to investigate the necessary measures, we must analyze the traffic-related air pollution condition and the mechanism of air pollution in the studied city.
In this chapter, the process of analysis of problems & causes is described.

(1) Analysis of traffic-related air pollution conditions

In the case of Jakarta, the concentrations of NO_2 and SPM were monitored by a simple survey method over a period of three days in September 1994. The equipment for measuring NO_2 concentration was placed at twenty-four locations along main roads and at intersections as well as in the center of blocks. For SPM, 4 points were surveyed. Sectional traffic volumes were counted at three representative points.

In this simple survey, the number of sites is limited. This makes it difficult to obtain an understanding of the real situation of air pollution of Jakarta. For estimating the concentration of overall areas or a point of the city, a traffic-related air pollution simulation model is used in this study. The limited simple survey data were used for the validity test of the simulation model.

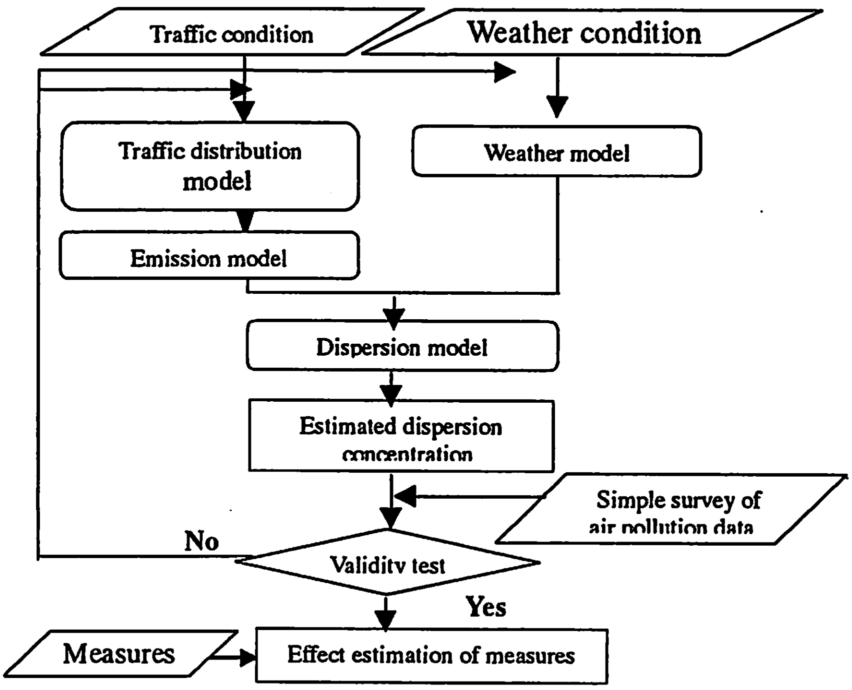


Figure 3 The simple flow chart of a traffic-related air pollution simulation model

The simulation model is composed of four major components: a transportation sub-model, a weather sub-model, an emission sub-model, and air dispersion sub-model. The transportation sub-model was used to forecast the spatial distribution of transportation activity. This sub-model is an adaptation of the conventional 4-step model for demand forecasting. The relationship between vehicle speeds and emissions per kilometer in this study was based on the functions compiled by Nitrogen Oxides Concentration Operation manual for Area-wide Total Pollutant Control (Air Pollution Control Division, 1995). With the function given, the average emission rate was estimated by the each type of vehicle for any average speed on a link. The calculated volume of emitted pollutants of each link are then used to determine the distribution of air pollution concentrations in the dispersion sub-model by using parameters specified the plume and the puff model depending on average weather conditions. As the classification of the weather stability, the Japanized Pasquill stability classification was used in study. The dispersion parameters were followed in the Pasquill-Gifford diagram. As transform

function between NO_x and NO_2, an approximate exponential form was used. The parameters were set, as followed from the experience data in Japan (Japan Transport Cooperation Association, 1995). By using the dispersion model, the concentration at any site can be calculated and the average concentration at each site was then obtained by summing up all concentrations from each link of the road network. The results were displayed as map in the proposed system.
These components are briefly described below in Figure 3, which shows a simple flow chart of the model.

For the traffic related air pollution simulation model, some related-data are needed. Weather data of Jakarta was obtained from the Weather Bureau of Jakarta. Since data on traffic volume and vehicle emission coefficients were unobtainable, they were estimated as below. In case of Jakarta, the OD table of trip generation in 1995 and 2000 were estimated from the data used for the "Outer Ring Road Project in Jakarta" of 1993 and the "Arterial Road System Development Study in the Jakarta Metropolitan area" of 1985. For estimating traffic related air pollution in 2000, the predicted number of vehicles and the planning population of Jakarta were taken into consideration. There were also no data on current vehicle emission factors for NO_x in Jakarta. Data of unregulated emissions period in Japan (1973) replaced them, taking vehicle conditions in the cities into account.

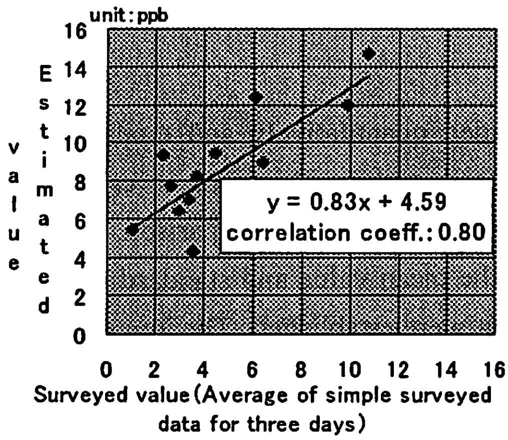


Figure 5 Validity test in Nagoya

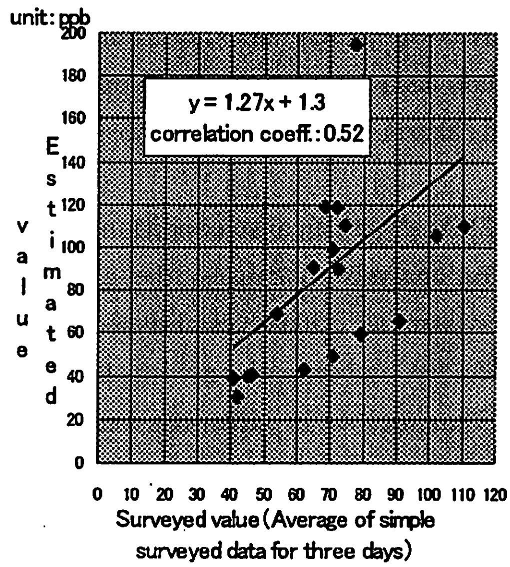
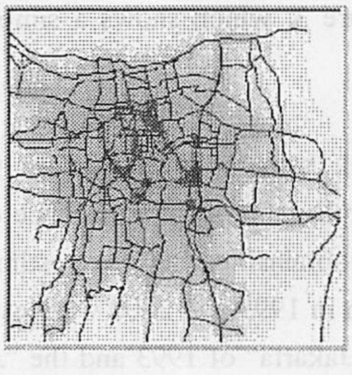
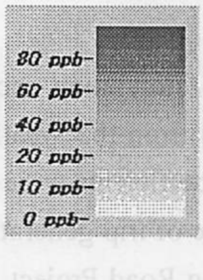


Figure 5 Validity test in Jakarta

The simulation model in the proposed system was already calibrated in a standard city, Nagoya. Figure 4 shows a comparison of NO_2 concentration between the monitored values by simple survey method and the estimated values by the simulation model in Nagoya. The concentrations of NO_2 surveyed in Jakarta were also used for verifying the reproducibility of the simulation model. Figure 5 shows the results of a validity test in Jakarta. Considering the simple survey over three days, the performance of the simulation model is thought to be enough for comparably testing the effectiveness of alternative measures as prototype system.

Figure 6 shows the present annual average concentration of NO_2 estimated, while Figure 7 shows the forecasts of annual average concentration in 2000, assuming that no measures are taken for the environment in Jakarta.





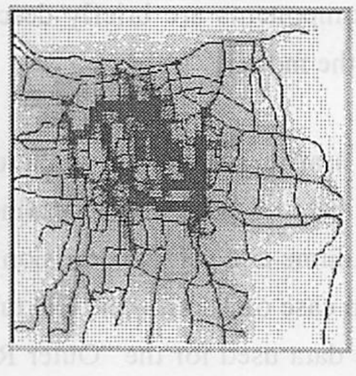


Figure 6 Distribution of NO_2 (1995)
(In case of present condition)

Figure 7 Distribution of NO_2 (2000)
(In case of taking no action)

Judging from the distribution in Figure 6, the areas where air pollution is serious, are still limited, while air pollution is widespread throughout the entire areas. Most of the central areas of Jakarta and the around of main roads are above the environmental standard of Indonesia (daily average 50 ppb). In the estimated results (in Figure 6), almost every area in Jakarta will suffer from most serious pollution. Some areas are estimated above 100 ppb.

(2) Analysis of cause conditions

For analysis of causes, the cause items are graded quantitatively and qualitatively by assessment criteria established inside the proposed system. Assessment criteria were decided by comparison with the standard cities in Japan. For city comparison, the data of 13 main cities in Japan has been used. Based on the mean value and standard variance of each item of those cities, the criteria for assessment were established. The items have been evaluated according to five ranks (A to E): Rank A being excellent and rank E being the worst.

For reasonable and objective analysis, international database would be more useful material. But they are not set yet. This study is now being accumulated in international database around the world in addition to the standard cities in Japan.

The main analysis results of cause conditions in Jakarta are summarized as follows.

1) Overall condition analysis of Jakarta

a. The problems of population increase, extension of urban area, traffic concentration, traffic jam and air pollution is serious and these conditions are forecast to continue.

b. There is not reasonable land use planning. So, private developers are able to make thoughtless city development.

c. The city of Jakarta has social, administrative and technical ability for solving air pollution.

d. Main problems of air pollution are derived from road traffic. Stationary sources form a relatively small part of air pollution sources.

e. In the dry season, air pollution is more serious.

2) Traffic-related condition analysis of Jakarta

<Pollution source>

a. Fuels having a lead ingredient are used and the rate of sulfur ingredient in fuels is high.

b. Some kinds of paratransits are popularized as public transportation in Jakarta except the main roads. The maintenance conditions of paratransits are very poor and this makes air pollution more serious.

c. Most of buses and trucks are the secondhand vehicles. They emit black exhaust fumes.

d. Vehicles are inspected every five years. At this time, emission inspection is carried out. However, the facilities of emission inspection are not sufficient and it is one of reasons that the system of emission inspection is not so effective.

<Traffic volume>

e. According to the increase of the persons of middle class, the increase in the number of cars is very high (40% increase over 4 years).

f. Most of the cars are made in Indonesia and the maintenance condition is relatively good.

g. Three in one regulation says a private car can enter Tamrin road only when it occupied by three people or more. However, it is not so effective because jobless youths will ride with a driver as dummy passengers for a very small sum of money.

<Traffic flow>

h. Since there is not a comprehensive enough plan, the traffic jams are serious at the conjunctional points between improved roads and unimproved roads.

i. The traffic volume exceeds the road capacity in the 60% on main roads.

j. Business facilities of and hotels derive large traffic volume and there are not appropriate regulations for parking.

k. Inadequate signal controls and railway crossings cut off the traffic flow and invite traffic jams.

l. The access modes on roads to railway stations are insufficient.

m. The train do not run punctually which is one reason that they claim such a low share of transportation.

n. There is not sufficient area in front of railway stations and it makes stations do not have terminal functions.

o. There are many kinds of railway vehicles. This is main reason that the parts of vehicles can not be supported efficiently and the stoppage rate of train service is high.

(3) Analysis of measure implementing conditions

The measure implementation conditions surveyed in the field survey are analyzed and evaluated in this step. Evaluated results have three ranks : implementing (○), planning (△), and not under consideration(X). For quantitatively grading measures, assessment criteria were decided by the expert group for field survey in the studied city. In case of Jakarta, all members of the committee attending field survey in Jakarta carefully discussed for deciding the rank of each measure.

The main analysis results of measure conditions in Jakarta are summarized as follows.

1) As measures against pollution source, the emission regulation is in operation at present and there is a plan to produce unleaded gasoline. There is also a plan for improving and increasing vehicle service workshops to cope with vehicle inspection.

2) As measures against traffic volume, the inflow regulation into central city areas and the traffic regulation of large sized truck by time zone are in operation. The improvements of bus and railway (subway) networks are also planned.

3) As measures against traffic flow, the improvement of the road network is planned. The arrangement of traffic laws and the improvement of traffic management systems are also planned.

4) The improvement of air pollution monitoring systems is planned. However, environmental aspects are not so carefully considered in urban and transportation planning.

4. PROPOSAL OF MEASURES AND CONSULTATION

In chapter 3, the steps of survey and analysis process were explained. These steps are needed for the analysis of the conditions of air pollution, causes and measure implementation. That is corresponding to the survey and analysis process of the studied city. As a next step, based on previous analysis results, the necessary measures are investigated by using comprehensive situation analysis matrix of causes & measures. The implementation priorities are also decided by using the inter-relationship diagram in this chapter.

4.1 Comprehensive matrix of causes & measures

After independently analyzing the causes and measures, a comprehensive matrix [R] could be set. In this matrix form, the evaluated results of causes [c] are written in the left part and the evaluated results of measures [m] are written in the top part. In the intersection parts of the matrix, the inter-relationships of causes and measures are displayed in color. The inter-relationships are derived from knowledge and various experiences concerning traffic-related pollution of developing and developed countries. It is common in cities everywhere. If one measure is very effective for improving some causes, the intersection parts of the matrix are colored red. In the case of an effective case, the intersection parts of the matrix are colored gray. If there is no direct inter-relationship between some measures and some causes, the intersection parts are not colored. Based on this matrix form, the mechanism of air pollution can be comprehensively understood in the studied city.
If the value of a cause ranked E, very effective and effective measures for solving the cause are scanned and listed from the matrix. In some cases, some measures are newly proposed and in another cases, some measures are supplementarily proposed for making up for weak points in the current measures. The comprehensive matrix form that is applied into Jakarta is shown as an example in the Figure 8.

Based on the comprehensive analysis of causes & measures, the main analysis results in Jakarta are summarized in the following sentences.

Most of cause items in pollution source (e.g., fuel ingredients and level of vehicle maintenance, etc.) are assessed as very low levels. Considering these conditions, the improvement of fuel ingredients and strengthening emission inspection should be urgently implemented as measures against pollution sources.
There is a lack of efficient mass rail transit systems commensurate with the size of the metropolitan area and the measure of inflow regulation into central city areas is not so effective. The improvement of public transportation for transferring from private cars to mass transportation should be considered more actively as measures against traffic volume.
Traffic jams are especially bad at the junctions of improved roads and unimproved roads and there is no complementary connection between bus terminals and railway stations. Considering these conditions, the plans of the road network and railway network are comprehensively considered for updating traffic flow.

4.2 Decision of implementation priorities by using inter-relation diagram

The outputs from the previous steps are only a list of measures based on their effectiveness for solving air pollution. The listed measures must be arranged and systematized for deciding the priorities of implementation.

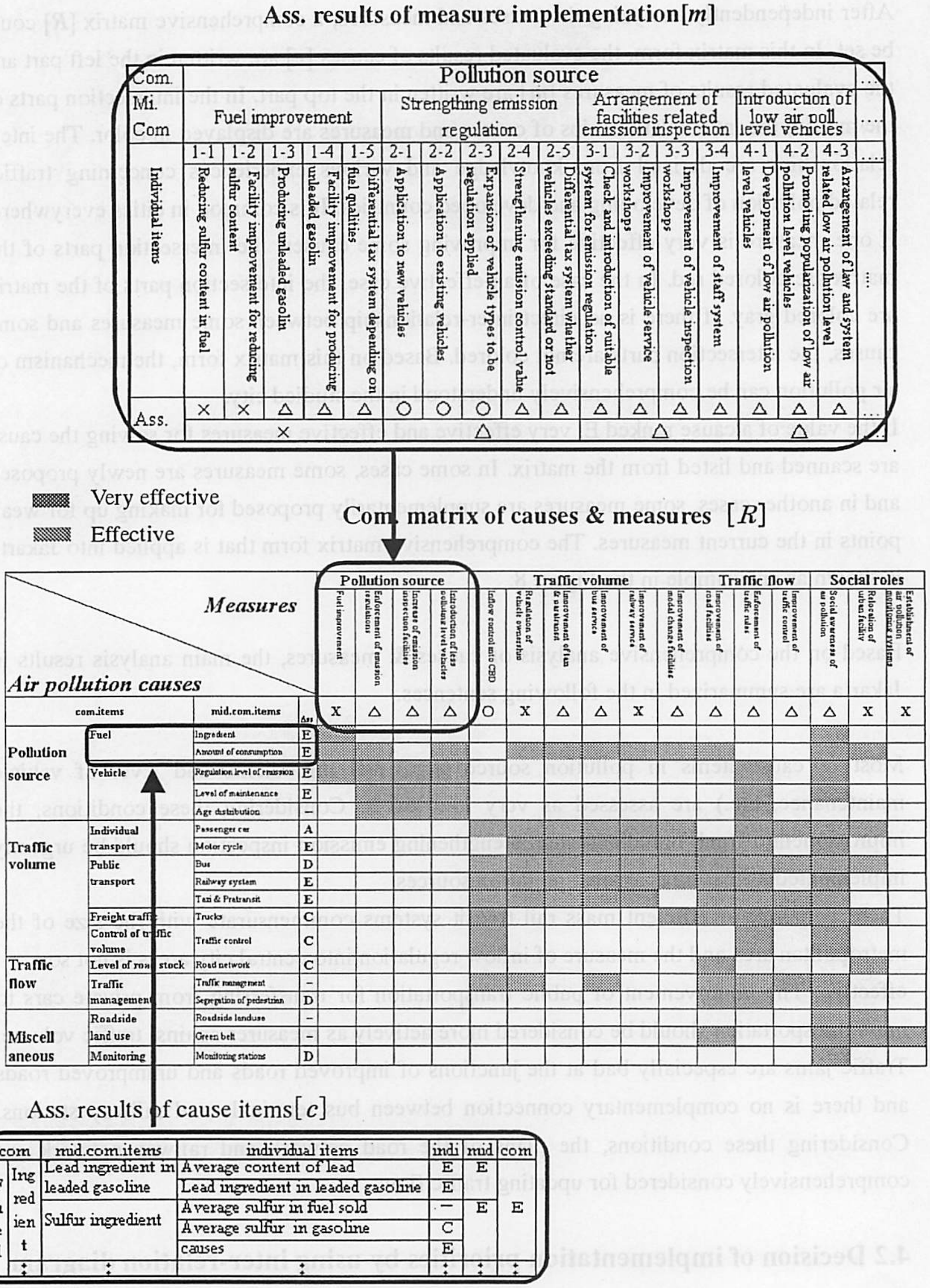


Figure 8 Comprehensive matrix of causes & measures

At this step, the implementation priorities of listed measures are automatically decided by using inter-relationship within the system. The inter-relationship between measures is constructed by the integrated information derived from knowledge and existing experiences of developing and developed countries. The inter-relation diagram is also considered common in cities everywhere. Among the inter-relation diagrams established in the system, a part of pollution sources is shown in Figure 8. In the inter-relationship diagram, measures are written in rectangular and causes are written in rounded corner rectangular. There are two kinds of arrows: solid line and dotted line. The solid line arrow signifies a pre-requisite relationship between measures (without precedent measures, successive measures will not be effective for solving related-causes). The dotted line arrow signifies the post-incentive relationship between measures (with precedent measures, successive measures will be automatically induced for solving the causes of air pollution generation). The usage method of the inter-relationship diagrams is explained as follows. As a first step, the evaluated results are keyed in the items of measures through the GUI. After being keyed in, the implementation priority of each measure is automatically judged by the inter-relationship diagram. For an example in Figure 8, although the emission inspection system is in operation, the maintenance level of vehicles is ranked E (worst).

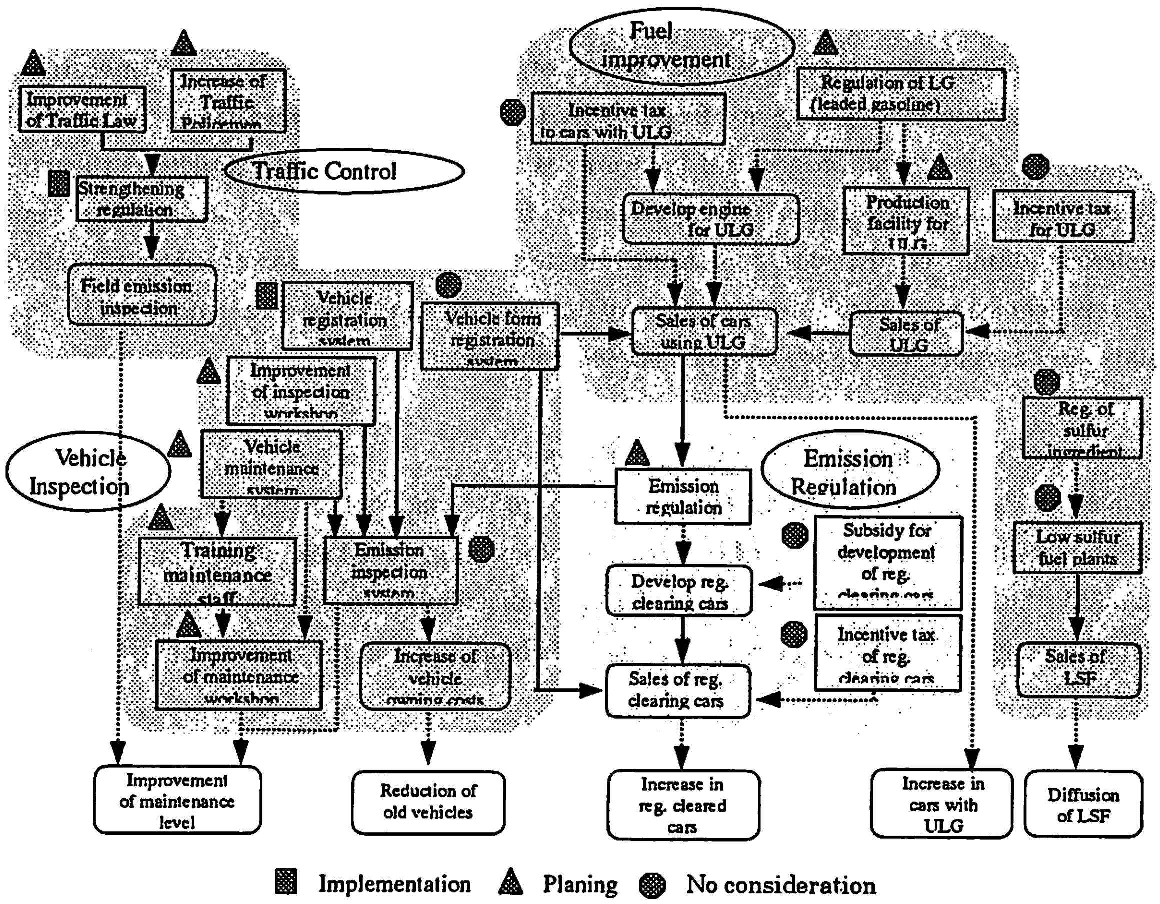


Figure 9 Inter-relationship diagram (the part of pollution sources in Jakarta)

The reason for this is that as the pre-requisite measures of the emission inspection system, the emission regulation and the improvement of vehicle service workshops are not in operation. In these circumstances, two pre-requisite measures should be urgently established and be in operation for increasing the effectiveness of the emission inspection system. By these, the implementation priorities of two pre-requisite measures are thought to be high. As explained in the example, the processes for judging implementation priorities are formatted by the knowledge-based "IF ··· THEN ···" rules in the proposed system. By the knowledge-based "IF ··· THEN ···" rules, implementation priorities of measures in city under study is automatically judged in the developed system for solving the facing problems. One example output of implementation priorities is shown in Figure 10.

After deciding the implementation priorities of listed measures, a program for measure implementation is automatically set and proposed to the system users. For proposal of a program for measure implementation, "IF ··· THEN ···" rules are also used here for an optimal program.

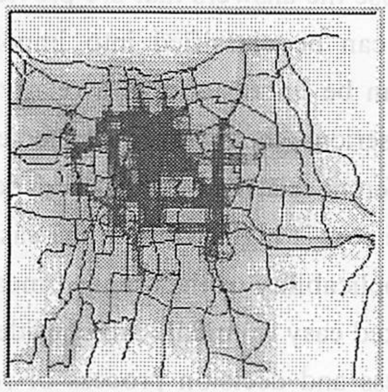
4.3 Trial to the Effects of main measures

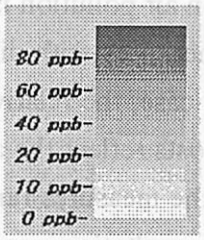
For testing alternative measures, the effects of main measures among the investigated measures in the previous step are foreseen by the air pollution simulation model. As the outputs of this step, the program of measures is suggested with the simulated effects and some related-examples already experienced by other countries for helping actual implementation. As alternative measures to test their effects, construction of railway systems, emission control, construction of urban ring highways, etc. were tried. These following cases are some trial cases of implementation.

1) In case of the construction of railway systems
As another example of the simulation results, figure 9 shows the case in which a subway that is already planned is completed from Koto station to Block M station. When it is operated, the concentration of NO_2 is spatially distributed in figure 9. In this case, the annual average concentration of NO_2 is reduced about 4 ppb in the central areas.

2) In case of emission control
As one example of the simulation results, Figure 9 shows the case in which the emission is controlled to the EPA emission regulations (established in 1988) that was suggested by the Bureau of Environmental Management of Indonesia (it is assumed to be controlled from 1998). The measure of the emission control in particular brought about a good effect on the situations in the studied city. In this case, as the improvement of emission volume, the

concentration of NO_2 is reduced in all areas. Especially in the central areas, about 25 ppb of the annual average concentration of NO_2 are reduced, compared to "taking no action". In this case, air pollution is highly reduced and the environmental standard could be satisfied in the most area of the city. However, in this case, the improvements of traffic volume and traffic flow will not be carried out. In the almost central areas of the city, traffic jams will be severer and the speed will slow down. These will present obstacles to the economic development of Jakarta. From the simulated results, however, it is clear that a measure of implementing emission controls is urgently required, in order to solve traffic-related air pollution.





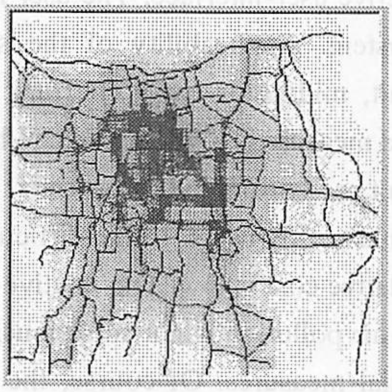


Figure 10 Distribution of NO_2 (2000)
(In case of the subway construction)

Figure 11 Distribution of NO_2 (2000)
(In case of emission control of EPA)

4.4 Discussion for the applicability of investigated measures

In this step, users discuss some possible problems, when the investigated measures are implemented. Supplementary measures and new measures can be scanned in the step of "analysis of causes & measures". These scanned results are only based on knowledge and experience. It is consequently general solution in cities everywhere. The special implementation conditions of the studied cities are not reflected in the results of the system. However, the results automatically proposed by the system have a special meaning that makes users such as traffic-related or environmental officers and engineers aware of necessary measures for solving their air pollution problem although the cost and particular conditions of the studied cities are not taken into consideration. This is an important result for understanding what is needed in their cities.

For a more realistic proposal of necessary measures, the standpoint of the studied cities must be reflected in the final proposal. From the standpoints of the cities, some measures are not acceptable because of the negative effects on the economic or political situation or the lack of financial ability for implementation. Before finally deciding necessary measures, the standpoint of the studied cities must be reflected as one kind of cost when a measure is implemented. Accurate evaluation of the cost & benefit of environmental goods such as some measures for solving air pollution is very difficult and different, depending on the conditions of countries. In this study, the cost is qualitatively input by users, taking into consideration their countries conditions. The cost includes all kinds of expenses (e.g., economical cost, political cost, technical cost, etc.). The process of consultation is operated by the user keying through GUI. The discussion results with system users are important in another sense. They include the information whether a measure is suitable or not in the studied cities. The proposed system extracts information on the applicability and checks the negative effect through discussion with system users. It is processed through an interactive user-interface. The user is requested to choose the answers that are provided by the system. Applicability of the scanned measures can be classified into impossible, difficult, middle or easy. The rank of applicability can be understood as a relative cost when a measure is implemented. When air pollution is serious, the measures ranked easy to difficult are considered as potential measures with different relative cost that is depend on the ranks set by users. In the difficult case, the relative cost is high, while in the easy case the relative cost is low. The relative costs reflect the applicability of the scanned measures. When air pollution is not so serious, the measures ranked easy to middle are considered as potential measures. Of course, the consultation process and decision process of relative costs are very simple, as compared to actual consultation and cost estimation. However, the main characteristic of the proposed system is a comprehensive diagnosis and prescription system as a preliminary survey system for traffic-related air pollution system. The proposed system cannot suggest all detailed solutions for traffic-related air pollution. Instead of suggesting detailed solutions, the proposed system is focusing on understanding the comprehensive situation of the studied city, based on the knowledge and experiences. In this study, a prototype system is proposed as a first step and the system will be updated step by step for establishing more detailed solutions.

Based on discussion results for implementation, the feasibility of the measures needed is decided by effectiveness/cost ratios. After deciding the feasibility of listed measures, a measure program is automatically set and proposed to the system users. For proposal of a program for measure implementation, "IF ··· THEN ···" rules are also used here for an optimal program. The final measures proposed by the system are decided by their feasibility. One example output of feasibility is shown in Figure 10.

The current applications to these cities have not yet been completed. We cannot present final measures for the city in this paper. We are now conducting further analysis not only based on the simulation analysis, but also from a socio-economic standpoint for finding out feasible and beneficial measures for developing cities.

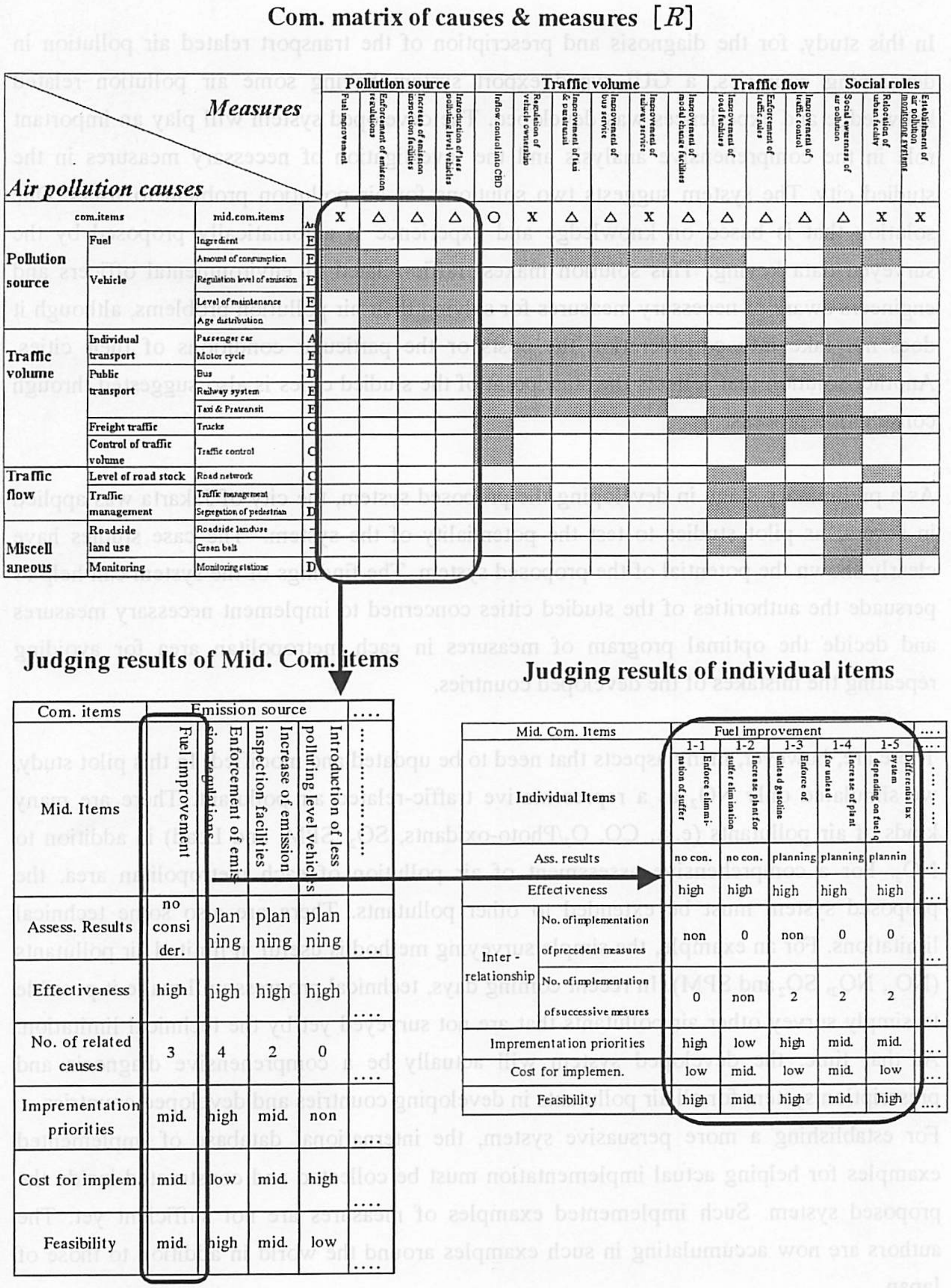


Figure 10 Example of the system output

5. CONCLUSION

In this study, for the diagnosis and prescription of the transport related air pollution in developing countries, a GUI typed export system having some air pollution related knowledge and experiences was developed. The developed system will play an important role in the comprehensive analysis and the investigation of necessary measures in the studied city. The system suggests two solutions for air pollution problem to users. One solution that is based on knowledge and experience is automatically proposed by the surveyed data keying. This solution makes traffic-related or environmental officers and engineers aware of necessary measures for solving their air pollution problems, although it does not take into consideration the costs or the particular conditions of their cities. Another solution that reflects the standpoint of the studied cities is also suggested through consultation process.

As a preliminary stage in developing the proposed system, the city of Jakarta was applied in several as pilot studies to test the potentiality of the system. The case studies have clearly shown the potential of the proposed system. The findings of the system can help to persuade the authorities of the studied cities concerned to implement necessary measures and decide the optimal program of measures in each metropolitan area for avoiding repeating the mistakes of the developed countries.

There are, however, many aspects that need to be updated and modified. In this pilot study, we simulated only NO_2 as a representative traffic-related air pollutant. There are many kinds of air pollutants (e.g., CO, O_3/Photo-oxidants, SO_2, SPM, and Lead) in addition to NO_2. For a comprehensive assessment of air pollution of each metropolitan area, the proposed system must be extended to other pollutants. There are also some technical limitations. For an example, the simple surveying method is useful in limited air pollutants (NO_x, NO_2, SO_2 and SPM). In recent coming days, technical progress will make it possible to simply survey other air pollutants that are not surveyed yet by the technical limitation. At that time, the developed system will actually be a comprehensive diagnosis and prescription system for all air pollutants in developing countries and developed countries.
For establishing a more persuasive system, the international database of implemented examples for helping actual implementation must be collected and constructed inside the proposed system. Such implemented examples of measures are not sufficient yet. The authors are now accumulating in such examples around the world in addition to those of Japan.

Although there are many aspects that need to be updated and be modified, these results confirm the system's effectiveness and support the further development of knowledge and experience-based system as a useful tool for improving air pollution problems in megacities. The benefits of the proposed system may not limit local air pollution abatement in the studied city but substantial benefits could also occur in the form of reducing global climate change, traffic accidents and congestion.

Finally, the authors hope the proposed system can be helpful for solving traffic related environmental problems of developing countries.

ACKNOWLEDGEMENT

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. Authors have developed the "Knowledge and experience-based expert system for transport-related air pollution in developing countries" as members of this project. The authors would like to extend their sincere gratitude for getting invaluable ideas and comments to all members of the committee for the project; MOT, Japan Transport Cooperation Association, Nagoya University, Japan Weather Association, Institute of Transportation Policy Studies, Prof. Nihei in Tokyo University, and Prof. Miyamoto in Tohoku University.

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