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# Managing Emergency Response of Air Pollution by the Expert System

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## 1. Introduction

Recently, the emergency preparedness of environmental disaster has been grown because of the climate change and growth of new technology in industry. The need to reduce the risk of major event of air pollution is of great concern. To ensure the quality of response management and reduce the loss in the air pollution event, it is necessary to design a reliable emergency response system. However, the phenomenon of air pollution is very complicated so it is very difficult to consider all possible factors in one system.

A well prepared response management plan should include the prediction and recommendation for the policy makers so as to reduce the possible damage of the disaster. This chapter sets out the method to improve both planning for emergency response of air pollution and recommendations to improve the effectiveness of this system.

The effect of air pollution includes the long-term and short term. Long-term effect of air pollution was controlled by the abatement program of source reduction. However, the short-term episode is more difficult to control because the emergency response is usually very complicated and related to many people in the neighboring area.

The environmental disaster, both from the natural and man-made release, has to be controlled by the well-designed management program. However, the consequence of the disaster was related to so many actions and regulations, therefore it is very difficult to make a quick and correct response measure only by the human. The supplementary system with the aid of computer system become more important in the decision making process.

The decision making system for air pollution management has to consider the appropriate method to avoid the damage from the pollution. Therefore, a complete database includes all the possible reason and consequence results should be included in this system. Beside, the

system should be able to deduce the possible consequence and suggest the best choice for the decision makers.

A case study was presents in this chapter. This study uses the experience in Taiwan as an example. Since Taiwan is a very small island with highest population density, the air pollution also causes severe problem for the public. Because the population density is as high as the on the top of the world, the air pollution response management system have also received more attention in environmental management.

The chapter was written in the following structure. The concept of air pollution management was described in the second section. Then the structure of knowledge bank was proposed. The data base and inference system was proposed and written in the following. Finally a conclusion of this system and the suggestion for the future research was followed.

2. Concept of air pollution management system

2.1. Definition of air pollution disaster and risk management pattern

Before going into the detail, we have to know the concept of air pollution management. An air pollution management system for emergency response could be described by figure 1. In this system, there includes a knowledge database, an inference mechanism, and the interface with the users and another resource. Because the system will influence many people and interest groups, so it has to be designed more carefully in order to get the optimum decision. This data base and inference mechanism is just used to ensure the reliability of the effectiveness of this system.

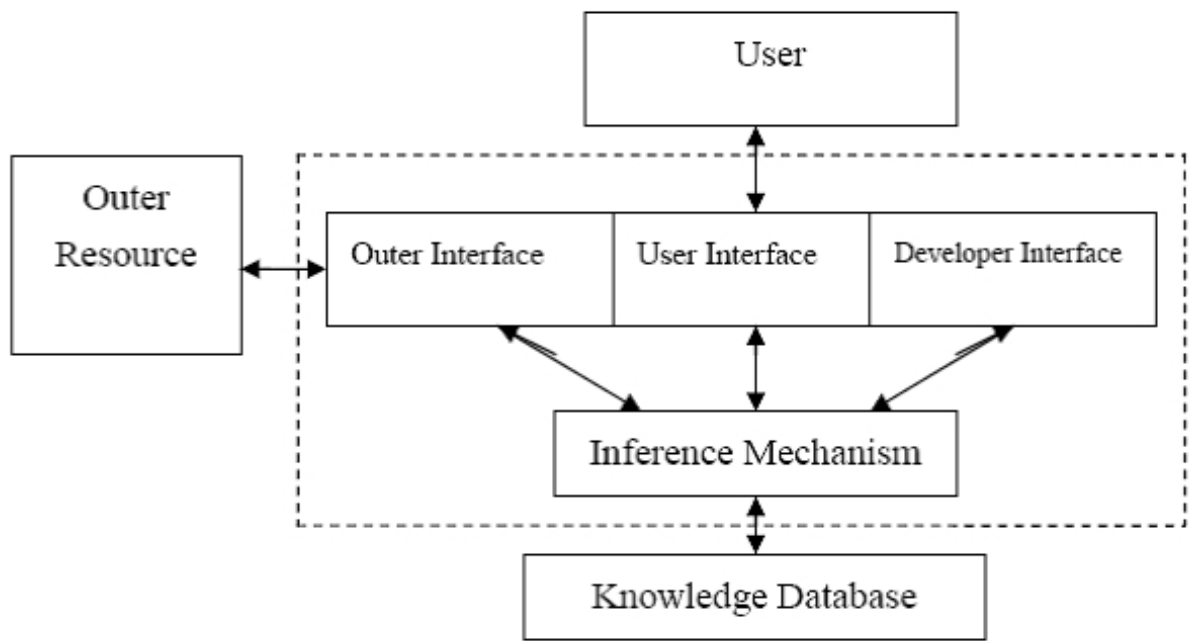
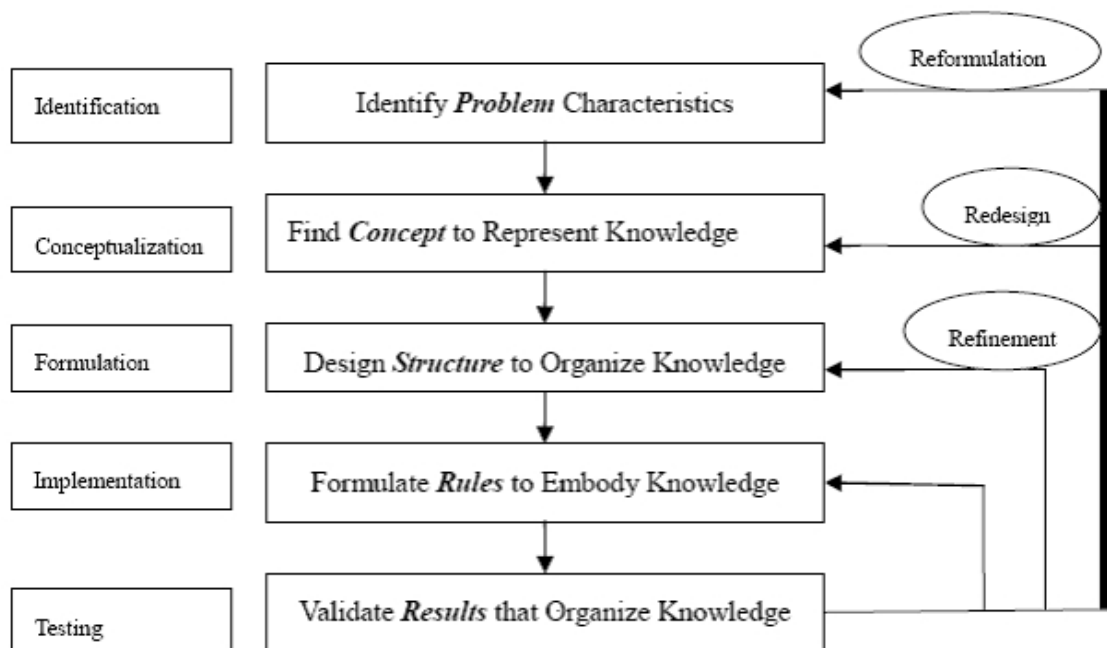


Figure 1. Expert system for air pollution emergency response

The design of this system includes the following steps as: (1) Identify problem characteristics; (2) Find concept to represent knowledge; (3) Design structure to organize knowledge; (4) Formulate rules to embody knowledge; (5) Validate rules that organize knowledge.

Every air pollution event has its characteristics; it can be represents by an appropriate knowledge. Then we design the structure to organize this knowledge, and formulate the mathematical rules to embody the knowledge so that it can be inference in the system. Finally, we have to validate the rules and organize all of this knowledge for the future forecasting.

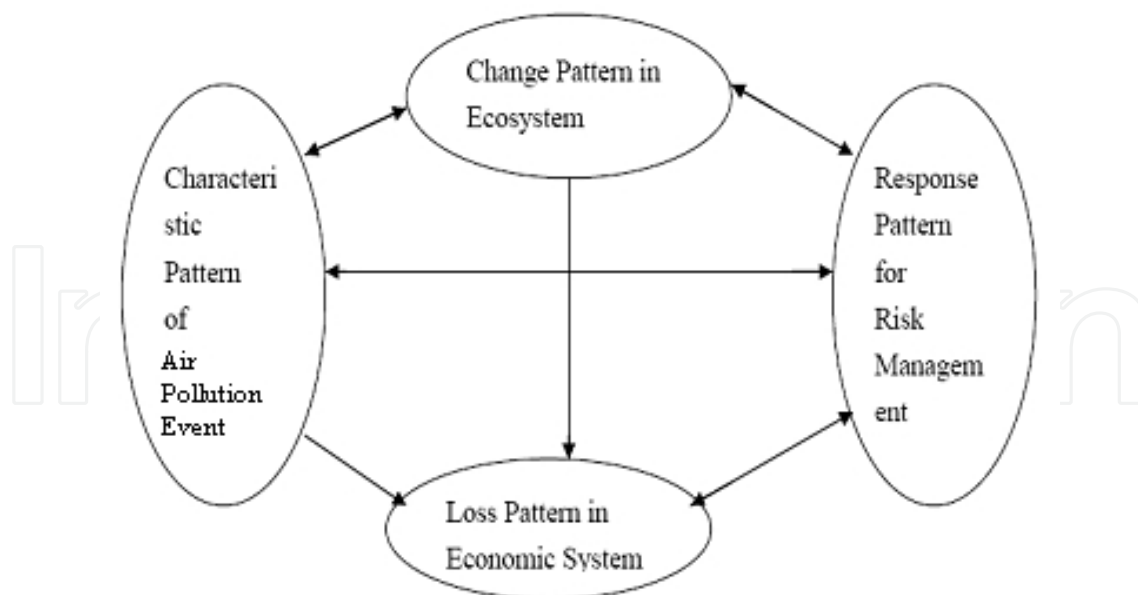


**Figure 2.** Flow chart for constructing an expert system

## 2.2. Identify the pattern system of risk management

The air pollution disaster is an accidental phenomenon in the environment; it can be represented by a mathematical pattern. The pattern structure of air pollution management can be categorized as the following four types as shown in figure 3. The first pattern is the characteristic of the air pollution episode itself. The second pattern is the change pattern in the ecosystem. The third pattern is the loss pattern in the economic system. And the final pattern is the response pattern for the disaster management.

Different episode has different characteristics, such as the dust storm, forest fire, explosion, and toxic gas leakage, etc. it will cause various types of damages. These will cause the damage in ecosystems and loss in economic system. Therefore, the change in these two systems has to be the well prepared management systems. A good management system should be able to concern all of these factors together. And suggest an optimum decision for the decision maker. However, it will include many criteria in the thinking, so the expert system has to be applied in the solution.



**Figure 3.** Pattern structures of environmental risk and its management

### 2.3. Define the space-time information system of air pollution risk management

In designing the expert system, the risk of air pollution event should be discussed first. Since the air pollutant or hazardous materials can be released into the atmosphere by accidents at plants, chemical processing, and other facilities. They may also release by transportation accidents. All of these events can cause the risk for the residents in the neighboring communities. Thus a precise way to estimate the possible damage to the community of the environment is indeed very important. The formulation of a disaster event has to be derived first.

The process of air pollution disaster management is a space-time information problem. In general, the space geographical information can be represented by the following equation:

$$I = \sum_{i=1}^m \left[ \sum_{j=1}^n \begin{bmatrix} S_{ij}(T_{ij}) \\ A_{ij}(T_{ij}) \\ T_{ij} \end{bmatrix} \right] \quad (1)$$

$T_{ij}(t_b, t_e)_{ij}$

Where  $I$  is the collection of space geographical information; it is the individual vector for the  $i^{\text{th}}$  item,  $j$  is the state of this item;  $S_{ij}(T_{ij})$  and  $A_{ij}(T_{ij})$  represent the characteristics of this item in time  $t_b$  to  $t_e$ . The inferences of the above equation are the following:

[Inference 1] If  $i$  is constant, then this equation represents the time series data of the same characteristic.

[Inference 2] If  $j$  is constant, then this equation represents the characteristic distribution in the same time.

From the above equation, all the events can be described and all the influence of this event in different space can be explained. The remaining parts are to transform the actual events into the mathematical forms for further inference.

## 2.4. Define the emergency response measure for risk management

For an air pollution disaster management system, there exists a domain of emergency response measures, defined by the following equation:

$$\begin{aligned}
 M &= (Action_1, Action_2, \dots, Action_n) \\
 &= (m_1, m_2, \dots, m_n) \\
 &= \sum_{i=1}^n m_i
 \end{aligned} \tag{2}$$

Where M is the collection of emergency response measure; Action i is the individual vector for the i<sup>th</sup> measure. Each action is represented by a symbol m; and there are m measures in the action domain. If the risk management system is good enough, there should have enough measure to solve the problem encountered by the air pollution. Therefore, we have the following inferences:

[Inference 3] If i is constant, then for each  $S_{ij}(T_{ij})$  and  $A_{ij}(T_{ij})$ , there exists a measure  $m_i$  in the emergency response measures domain.

[Inference 4] If j is constant, then for each  $S_{ij}(T_{ij})$  and  $A_{ij}(T_{ij})$ , there exists a measure  $m_i$  in the emergency response measures domain.

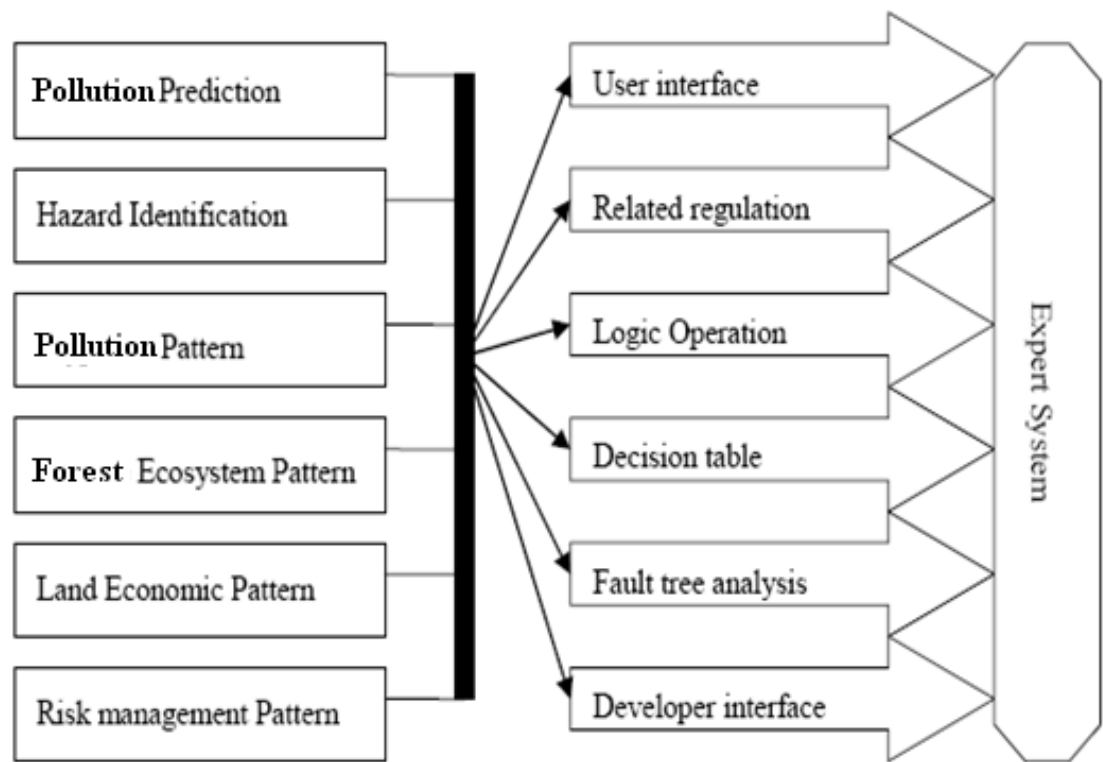
Different actions have different effectiveness. For example, the authority can stop the emission of air pollutants from the plant in case of necessary. Or they may restrict the activity of community people when there is a need to reduce the emission from the sources. Most of the action related to the benefit of the community people, so different divisions of the government has to be involved, like the local government, environmental protection agency, chamber of commerce, and regional development agency etc.

Not every action has a significant effect on the reduction of disaster, and they costs different budget. Thus we have to be very careful in selecting the actions. All the assembly of these actions is the policy of the government. It is recommended by the expert system.

## 3. Knowledge-bank analysis

### 3.1. Construct the modeling base for the expert system

The knowledge bank of an expert system is shown as figure 4. There are different types of knowledge stored in this system, like the events pattern, the change pattern of economic system, the change pattern of ecological system, and others.



**Figure 4.** Intelligent knowledge-based expert system

The entire possible pattern, such as the pollution prediction, hazard identification, pollution distribution, forest ecosystem, land economic, and risk management are included in the knowledge database. With this information, the system is able to forecast the possible outcome of the pollution disaster so that the residents can determine the best prevention strategy. Other tools like the logic operation, decision table, and fault tree analysis technique should be included. Finally, a developer interface and the user interface have to be designed very carefully.

The knowledge bank contains the model bank, pattern bank, and regulation bank as below. [5] There are three main modeling activities which included in the expert system: (1) contingency modeling, (2) short term modeling, and (3) accidental, or release modeling [6].

Contingency modeling is to present concentrations for specific chemicals and emission, which may be encountered at a possible release place. Short term modeling is to calculate concentrations occurred in a short periods. The third modeling, accidental release modeling, is perhaps the most critical to emergency managers, which includes natural or accidental release. This type of release modeling is performed soon after a release occurs and is proposed to give immediate responses.

**3.2. The model bank for expert system**

In designing the expert system for air pollution management, we have to analysis the necessary model as the tool for choosing the correct response measures. Three major model



banks should be contained in the system, which are meteorological model, air quality model, and economic model.

### **1. Meteorological model:**

The meteorological model includes the following:

1. Wind field model
2. Temperature variation model
3. Pollutant path prediction model
4. Terrain model
5. Cloud model
6. Vertical wind distribution models
7. Remote sensing generated meteorological parameter model

The wind field model helps us to know the possible damage of the episode. Temperature variation model provide us the diffusion capacity of the atmosphere. The pollutant path prediction model helps us to identify the duty of the polluter. A terrain model provides us the information for the safety management of this event. The cloud model is benefit for the estimation of precipitation of pollutant. And the vertical wind distribution model provides us the understanding of vertical diffusion capability of the atmosphere.

### **2. Air quality model:**

There are several approaches to calculate air pollution diffusion. The most famous are the following three types.

1. Gaussian diffusion model
2. Trajectory model
3. Grid model

The above three model has different capabilities. Gaussian diffusion model is suitable for the near field forecasting. Trajectory model are often used to know the source-receptor relationship and suggest the possible decision for pollution abatement. The grid model can treat the photochemical reaction and often used in the implementation management program of air pollution.

Recently, the improvements in computer technology have significantly improved the speed and accuracy of air quality models. These models have been found in many different areas from ensuring regulatory compliance to assessing human exposure to natural disaster, accidental release, and intentional air pollutant transport.

### **3. Economic models:**

The economic models include the following:

1. Housing damage model
2. Personal injury and death model
3. Agricultural loss models
4. Indirect economic loss models



## 5. Post-disaster reconstruction costs model

### 3.3. The pattern bank for expert system

Three mathematical methods could be applied in the treatment of pattern in this research, which are: (1) Statistical pattern ;( 2) Fuzzy pattern ;( 3) Neural-network pattern. [2] [3] [4] [7]

In the system, we define the following systems: (1) Wind pattern; (2) Weather pattern; (3) Source pattern ;( 4) Population pattern.

### 3.4. The regulation bank for expert system

The risk management should follow the present regulations; therefore, a regulation bank for response measure is necessary in the management system.

### 3.5. The action bank for expert system

The action includes different economic models as the following.

1. Reinsurance compensation model
2. Super fund models
3. Major disaster securities market model
4. Social public disclosure models
5. Education and training model
6. Emergency response models
7. Human resource models

## 4. Data base analysis and inference system

### 4.1. Geographical information systems

The tool capable to handle the figure and characters simultaneously is necessary for the research of air pollution emergency response system. The concept of geographical information system (GIS) could be the answer. GIS are tools that allow for the handing of spatial data into information. A lot OF GIS has been developed and applied in diverse field. For example, the GPS satellite system, the web-digital map, and the remote sensing technique, etc. They are all built with GIS as the core technology.

Geographical information system has several advantages over the traditional database. The major advantages include different treatment of characters, the ability to treat the map data, and desirable property to pose the data on internet. The tool contains report generating a summary to analyze the area affected by the air shed.

The GIS has the following subsystems:

1. A data input subsystem that collects and preprocesses spatial data from various sources. This subsystem is also largely responsible for the transformation of different

types of spatial data(i.e. from isoclines symbols on a topographic map to point elevations inside the GIS) [1]

2. A data storage and retrieval subsystem that organizes the spatial data in a manner that allows retrieval, updating, and editing.
3. A data manipulation and analysis subsystem that performs tasks on the data, aggregates and disaggregates, estimates parameters and constraints, and performs modeling functions.
4. A reporting subsystem that display all or part of the database in tabular, graphic, or map form.

#### 4.2. Inference mechanism for the expert system

Logical formula operators allow us to compare values and evaluate the results. When two values are compared using logical operators, the result is either true or false. Logical operators are available in the Compute Wizard if/then/else formula menu as the following:

The four quadrants	
Conditions	Condition alternatives
Actions	Action entries

**Table 1.** Example for conditions and actions

The inference mechanism in the decision supporting system includes the decision table, logic gate, decision tree, and fault tree etc. Decision tree analysis will be applied in the system for decision support. A decision tree is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility.

In this study, we use the IF/THEN in the emergency response system. Table 2 is the example of decision for an episode by the IF (information) / THEN (action) operator.

#### 4.3. Models for air pollution emergency management

Different kinds of pattern model for air pollution management are listed in table 3.

### 5. Case study results and discussion

#### 5.1. Expert system for air pollution management

In this study, we use the dust storm as an example for the emergency response system. A framework for the expert system was described in this section. This system provides a easy-to-use, real-time access to pollution concentration predictions and consequence analysis. The system enables us to rapidly determine hazard areas, affected population, meteorological conditions, and relevant geographical information

IF	Logical operator	example (information)	THEN(action)
>	greater than	<b>concentration</b>	activities prohibited
<	less than	<b>distance to hot spot</b>	warning
>=	greater than or equal to	<b>emission amount</b>	warning
<=	less than or equal to	<b>distance to hot spot</b>	activities prohibited
=	equal to (comparison)	path	broadcast
!=	not equal to	<b>trajectory</b>	<b>dust storm</b>
&&	AND	location and path	broadcast
and	AND	wind direction and wind speed	broadcast
	OR	rainfall or runoff flow	alert
or	OR	radius or distance	warning
!	NOT	<b>particle concentration</b>	warning

**Table 2.** IF (information)/THEN (action) operator

	Disaster Pattern	Air model pattern	Economic Pattern	Risk management Pattern
1	Wind field model	Gaussian diffusion model	Housing damage model	Reinsurance compensation model
2	Temperature variation model	Trajectory model	Personal injury and death model	Super fund model
3	Pollutant path prediction model	Grid model	Agricultural Loss Model	Major disaster securities market model
4	Cloud model	Hybrid model	Roads and bridges damage model	Social public disclosure model
5	Vertical wind distribution model		Indirect economic loss model	Education and training model
6	Terrain model		Post-disaster reconstruction costs model	Emergency Response
7	Remote sensing generated meteorological parameter model -		-	Human resource model

**Table 3.** Four types of pattern in the emergency response system

Dust storm is a meteorological disaster which comes from the Mongolia area of northern China. The main reason for the formation of dust storm is the overdeveloping and the global warming which induce the soil become desert. The strong wind blow also increase the number of dust storm event year by year. This phenomenon also affects the neighboring area such as Korea, Japan, and Taiwan etc. [6]

In order to realize the dust storm disaster, many researches has been made recently and the database was build. Most of the information about the dust storm was monitored by the meteorological and environmental monitoring system followed by the data processing procedure.

The information generated in the process was largely in the form of figure or character. Although it is convenient to understand, the time consuming in processing these information is too long. The new architecture in this study is capable to offer a function that enables us to search the map data directory from the dust storm event. The main advantage for the new architecture is to simplify the search work and save the time for searching dust storm event.

## **5.2. Design and capability of the emergency management systems**

The case study described here referring to the design and algorithm of a dust storm event response system. The system was combined with the geographical information system and was called "DSGIS (Dust Storm Geographical Information System". DSGIS is an interactive geographical information system for dust storm research and has been developed to enhance the understanding of dust storm phenomenon and to offer a more convenient environment for the researchers and public.

The concept of geographical information system and supporting database system was applied in DSGIS for planning of the figureizational operating system of dust storm event. It enables use of digitization information to search and treat the dust storm event information.

There are three major concerns in implementing a dust storm geographical information system as the following: programming language, database, GIS tool, and interface.

Visual Basic was chosen to be the programming language of this system. The database applied in the preliminary system is "ACCESS" developed by Microsoft. GIS Design tool "ArcGIS ENGINE" supplied by ESRI was used in this system. And there are three interfaces in the system: (1) User Interface (2) Developer Interface (3) Outer Interface.

## **5.3. Design results of the expert system for managing air pollution**

The dust storm events were gathered in the DSGIS database system and combined with the air quality monitoring station data.

In planning the database structure, the monitored data were collected first. A standard form was suggested to be the format of this database. There are five index of air pollutants in each monitoring station, they are total suspended particulate (TSP), sulfur dioxide (SO<sub>2</sub>), nitrogen

oxide (NO<sub>x</sub>), carbon monoxide (CO), and ozone (O<sub>3</sub>). The database was designed based on the above monitored information. However, the content of this system will be revised and expanded in case there is any change of demand for this system.

The dust storm determined the air quality, mainly in particulate. However, the concentration change during the dust storm period was also increased by the researchers. The air quality index PSI is automatically calculated by the above five air pollution concentration value and categorized as suggested by EPA. The core system and algorithm for DSGIS is described in the system. Following the database structure discussed in previous section, the infrasture of DSGIS is shown in figure 5.

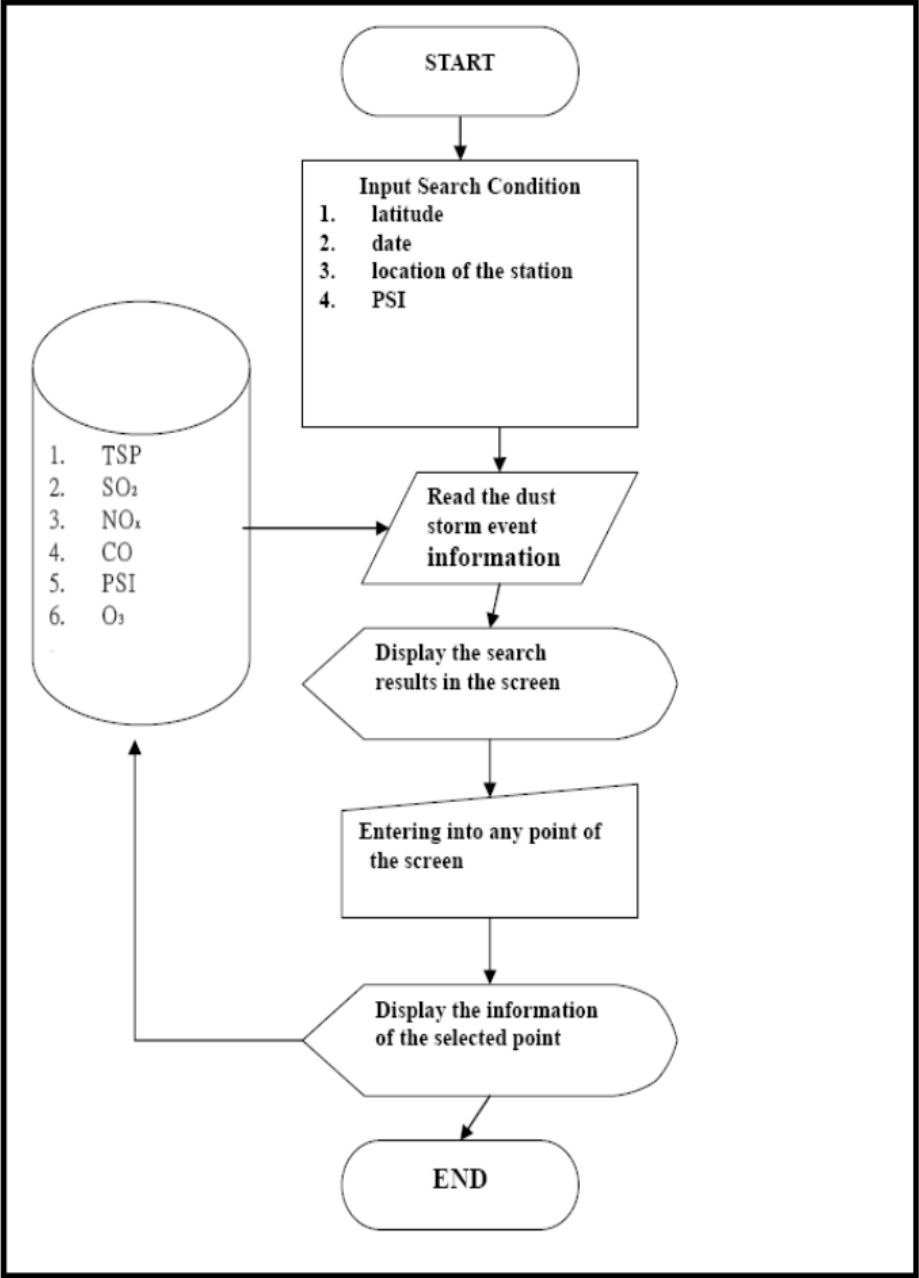


Figure 5. The Dust Storm GIS system (DSGIS)

PSI	SO2	CO2	NOx	O3	PM
62	5	1	72	75	54
71	7	1	33	92	61
67	6	0	60	70	77

**Figure 6.** Operation environment

The order of the system structure can be explained as in figure 6. The selected place or dust storm event can be input from the interface of the screen. Also, a “map searching” method was developed in this study. This method enables us to search a station directly from and display the information the users want to know. The detail of each step is described as the following.

### Entering into the system

The DSGIS will download the data automatically from the database of the selected zone where the user entering into the interface of the operating environment.

### Input the search condition

Four search conditions can be used as the search condition, they are:

- Latitude: input two sets of number of longitude and latitude such as (123, 23) and (121, 25). The number sets represent all the geographical information within the four points of the four numbers.
- Date: input year, month, date, these data can be input simultaneously or separately, e.g. the data 20070409 represents all the data in April, 2007.
- Location of the station: Input the station's number or the name of the station. It is also permissible to input two longitude and latitude to include all the stations within this area.

- iv. Select the number of PSI as it is defined and all the information within this range can be retrieved.

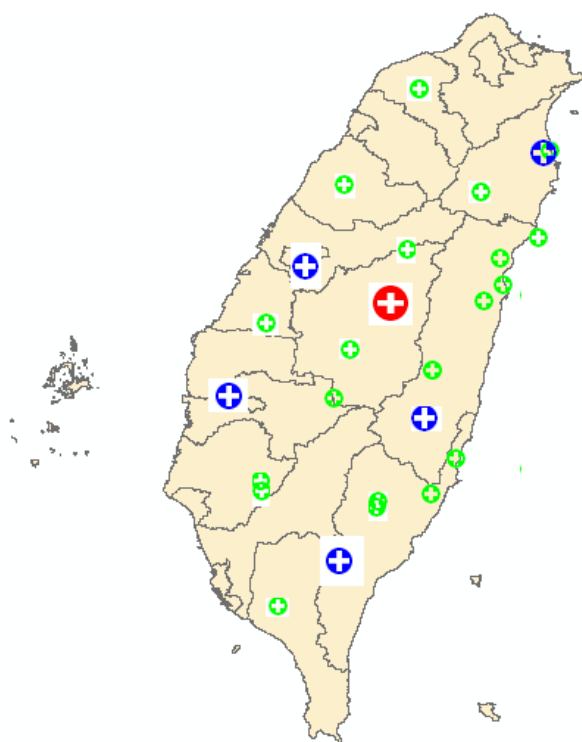
#### Display the search results (Fig. 6)

The information consistent with the search condition will be displayed. The information consistent with the search condition will be displayed in the screen on its location with the following sign as ☉, ●, ★, ☆, ▲, △, ♂, etc. .

#### View the search results (Fig.7)

When the search results were displayed, the DSGIS also allows the users to select the station directly through the mouse acted on the screen. More information about this station will be displayed consequently.

The version one of DSGIS has already completed. The structure of each component remains very flexible for the future application and adjustment of this system.



**Figure 7.** Search results

### 5.4. Numerical weather prediction bank of the expert system

In order to have precise results in the expert system, the numerical weather prediction model has to be applied. The prognostic data from numerical weather prediction models is suggested. The weather models predict future three dimensional atmosphere states by solving the conservation equations for mass, momentum, and thermodynamic energy. These models represent the relevant physical processes for moisture, cumulus convection, and radiation, and sub grid-scale turbulence.



### 5.5. Atmospheric transport and diffusion models of the expert system

Some models were suggested in this system, as listed in Table 4.

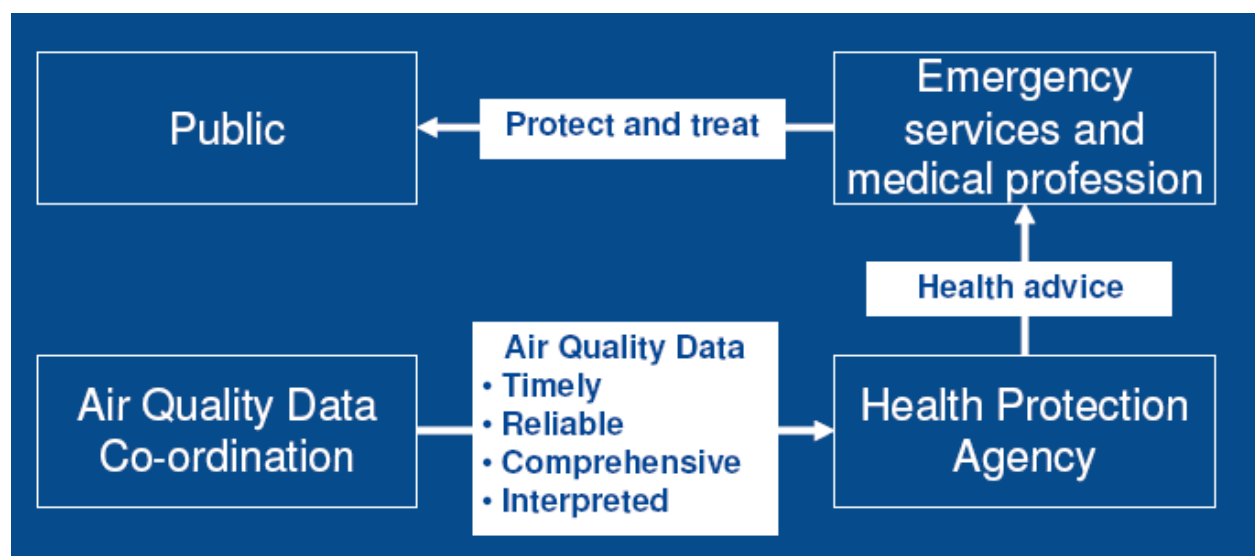
Air model pattern	Name of the models
Gaussian diffusion model	1. ISCST 2. AERMOD
Trajectory model	1. CALPUF 2. GTx
Grid model	1. TAQM 2. CAMx 3. WRF

**Table 4.** Atmospheric transport model used in the system

### 5.6. System validation and supporting databases of the expert system

The supporting database is important because the changes in metrological conditions and in emission strengths may affect the air quality.

A supporting database for the monitoring of the air quality data is important as explained in figure 8. the source distribution example of a county is shown in figure 9. the calculated pollution concentration in northern is shown in figure 10. Finally, the estimated social cost cause by air pollution in each district was shown in figure 11 as a for the decision maker.



**Figure 8.** The use of air quality monitoring data in the emergency response management system

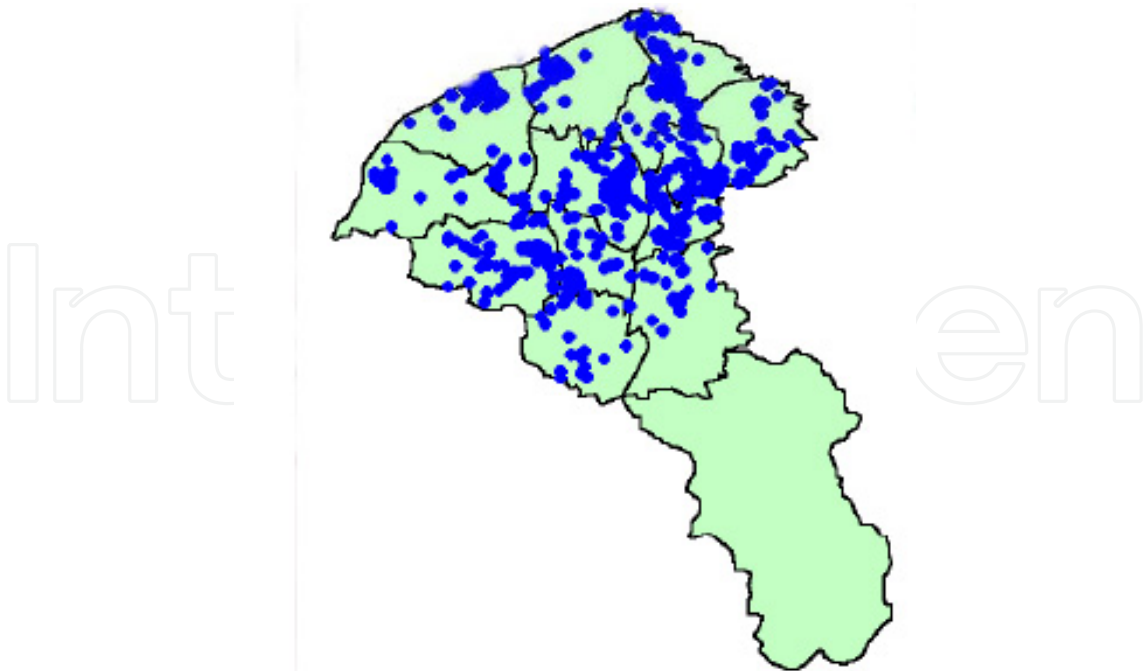


Figure 9. Example of the source distribution diagram in a county located in northern Taiwan

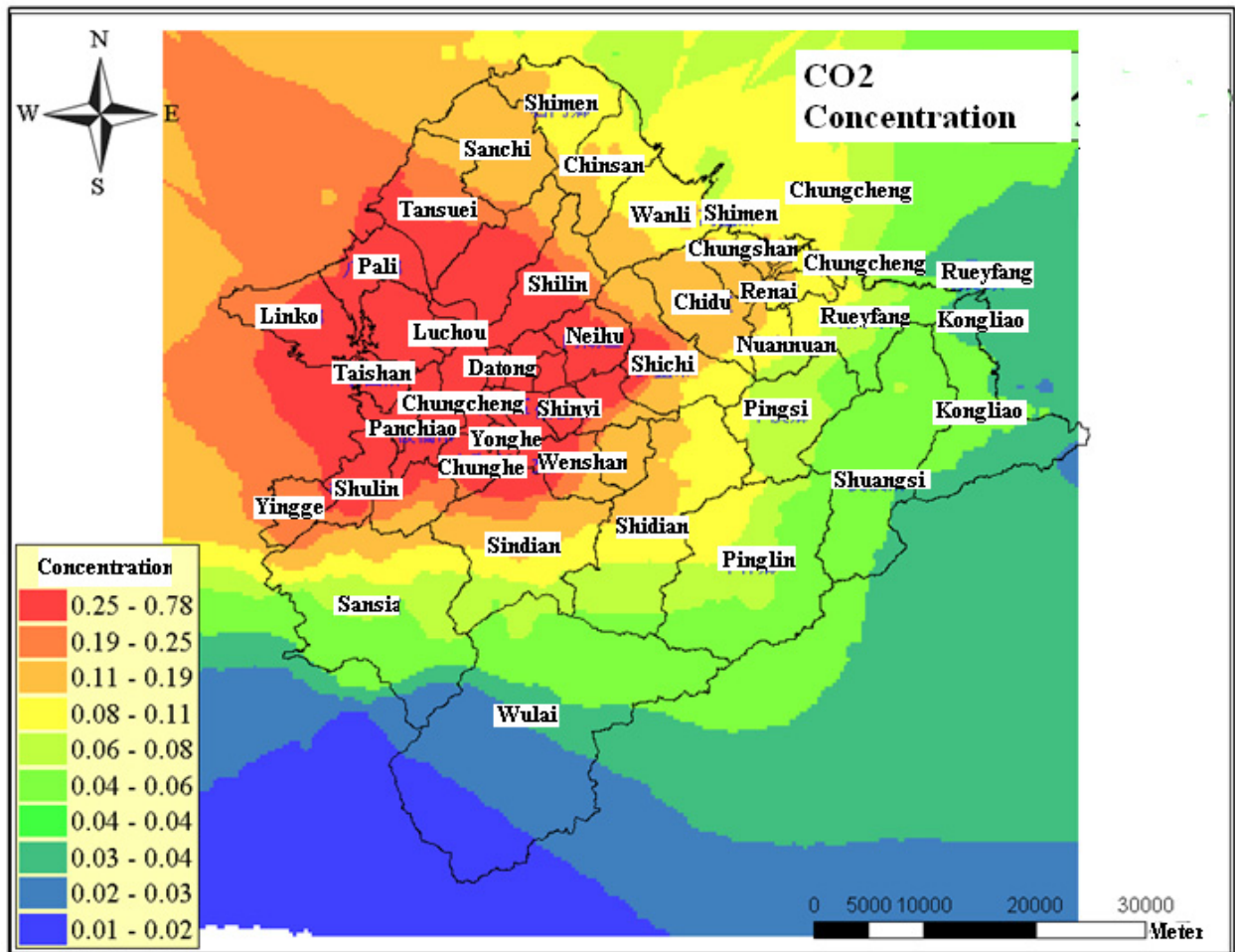
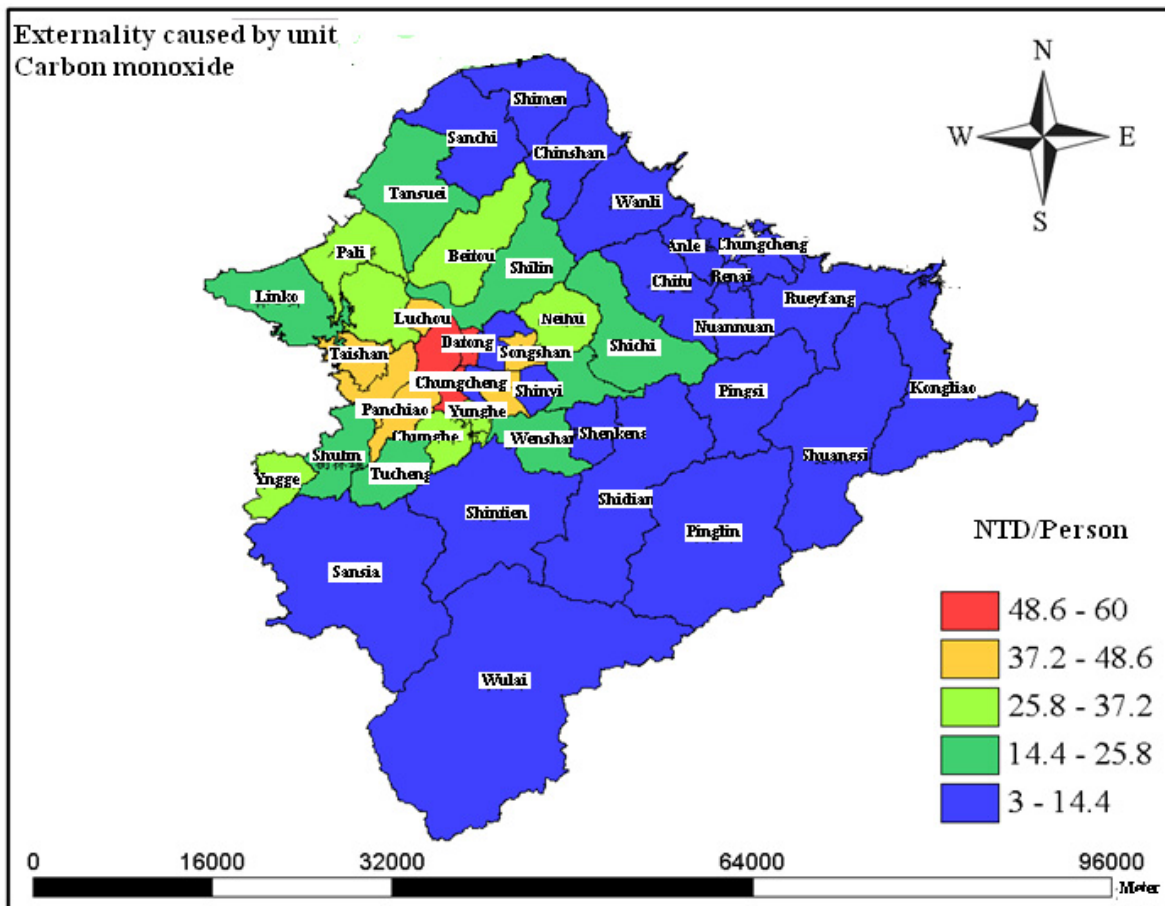


Figure 10. Predicted distribution of the pollutant concentration in northern Taiwan



**Figure 11.** Predicted social cost of pollution in northern Taiwan

## 6. Conclusion and suggestion

The intelligent expert system for air pollution emergency response was established in this study. The dust storm event geographical information system was studied and a knowledge-based decision support system for emergency response and risk management was established. The mathematical pattern relationship of air pollution effects on neighboring area and the corresponding response measures were included in this system. The decision maker can specify the procedure and minimize their human error in the decision process.

The performance results indicate that the function of DSGIS is acceptable. Generally speaking, DSGIS is a useful tool for taking the necessary knowledge and information about the dust storm. In addition, it also provide more convenient operating interface for the users. The concept of "map searching" is more convenient than the traditional searching methods. The performance results also show that the effectiveness of the DSGIS in searching the event is reliable and acceptable.

Since this system is designed on a module-based feature, it is easy to expand the application to more cases. Future work includes development of other independent module for individual event and gathers more information about the event into the database.

## Author details

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