Fuzzy Optimization in Decision Making of Air Quality Management

Wang-Kun Chen and Yu-Ting Chen

Abstract. This study presents an optimization method in fuzzy decision making of air quality management. The optimization method presented in this chapter gives the mathematical representation to find the equilibrium point. How to obtain and express these optimal data depends on the fuzzy optimization techniques. The methodology and algorithm of fuzzy decision making process by interactive multi-objective approach and iterative optimization method are described, with the application in the process of air quality management. This paper also provides the interactive multi-objective model and iterative calculation method for the application of air quality management. First, the comparison of model output and field monitoring results was discussed, and then the experimental outcome of interactive fuzzy optimum model was presented. Secondly, the comparison of optimum decision from different decision makers was considered, and the experimental outcome of iterative fuzzy optimum model was presented. The combined approach of interactive and iterative method for fuzzy optimization model makes the decision of air quality management more accurate and pragmatic.

Keywords: Fuzzy decision making, Optimization method, Air quality management.

1 Introduction

1.1 Decision Making for Policy Maker

Decision making analysis is a very important routine task for management. Decision analyst decides what kind of strategy to take from the data they obtained

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every day. Their decision will affect the future operating of an enterprise and many people's welfare; therefore, such decision must be made carefully. However, decision making analysis is a very difficult job, because the data comes from many different sources, and its credibility is not the same. Finally, what is believable? This is the biggest difficulty faced by policy-makers. In addition, what kind of message is provided among large amounts of data? These factors must be considered when conducting policy analysis. Fortunately, big data analysis techniques provide us the solution in this respect. Through big data analysis, we can get a more accurate analysis result.

How to get a reliable decision is the issue which policymakers continue to consider. The results of decisions are usually ”Yes “or “No”. And the data support decision may come from simulation results of the theoretical model or real observed results. If there is a difference between the two, what can be trusted for the decision-makers? The analysis results from theory provide observation mechanism of detailed changes. However, if the assumptions have errors, it can easily lead to erroneous results. That's why the results of theoretical analysis need to be verified through empirical analysis.

In addition to theoretical analysis and real observations, we also often get the support of decision-making through the expert. Because the experts have many valuable implicit knowledge, these knowledge is unable to acquire by theoretical models or real observations. While how is this valuable knowledge of experts join our decision-making process? The expert knowledge is usually hidden and unknown, but appears to be very reliable. This situation is a problem faced by policy makers, in the same way, how will this knowledge be put into our decision-making process. If in another case, the opinions from different experts are not the same, what people really can believe? Is there a solution to based on the advantages of the above three methods to get the best solution for decision-makers? It is an issue to be discussed in this article.

1.2 Review of Previous Studies

Air quality management is a very typical problem of decision analysis, it is related to the above three dimensions. As such, how the decision analyst obtains the message from above three sources to make the best judgment become the problems they faced every day. This chapter described the methodology of the decision analysis which combines the three issues. Theoretical development and its characteristics are presented. The experiment results are also shown in the article.

Before discussing this article, first, make a review of the past research that scholars have done. The representation of observational data and theoretical results of the model exist in all walks of life. So long, many scholars presented their views. (1oldstein and Landoritz, 1977) (Gustafson et al,, 1977) Sasaki first proposed in Calculus of Variation to optimize the best of meteorological data, to improve the consistency of observational meteorological data and results from meteorological model. And because air pollution is increasingly importance for everyone, Heimbach and Sasaki apply it to the assessment of air pollution. (Heimbach and Sasaki, 1977) They deal with the question of discrepancy between air quality monitoring stations and results of diffusion model. However, due to the large number of air pollution sources, his research has not described how to deal with the problem of value inconsistency between pollution sources and monitoring station.

Liang further developed his theory of optimization so that the theoretical model of air pollution can be capable of interaction with actual observed value. The model tries to have a good balance between each other. The constrained conditions of this theory were derived so that policy makers can have good space to determine what extent to be used. Thus, their decision will be the most realistic situation. His control theory was divided into two parts, strong and weak. And a parameter was derived to represent the degree of interaction between the two. There are also a lot of practical applications done by his theory. (Liang, 1979)(Liang, 1980)(Liang and Young, 1980)

Hsieh and Liang together use the finite element method to interact the information between the results from numerical models and observational data. (Liang and Hsieh, 1980) But they did not take into consideration of the air pollution sources. Liang and Lee take the example of carbon monoxide pollution in Taipei and apply the calculus of variation method for analysis. (Liang and Lee, 1980) Liang and Lee take the example of sulfur dioxide pollution in Kaohsiung to make good assessment between the values of observations and theoretical output. (Liang and Lee, 1980) And Chen and Liang use multivariate statistical analysis to optimize the value of model and observation (Liang and Chen, 1981)

However, Sasaki with the above researchers only takes into account of comparison and interaction between observations and model results. They did not consider the participation of wisdom from experts. And no doubt the wisdom of experts is a very important part of the decision analysis process. If not applying this part, the result is bound to be something omissions in the decision-making process. How to solve the problem of expert’s wisdom participation is the focus of this article. In this chapter, the author tries introducing fuzzy decision theory to have a good inter-connected among the above three. Using fuzzy mathematics and iteration procedure, the opinions of expert’s can be integrated. The expertise and advantages could give full play to obtain the best strategy. (Novák, 2005) (Torof, 1970)

Nevertheless, the above research only focuses on establishing the mathematical representation of the decision making of air quality management by Calculus of Variation. And these studies are mainly on the comparison of model output results and field monitoring results. In addition, there is very little discussion about the application of granular computing in air quality management. Although there are some researches which applies the fuzzy method to forecast the air quality. It is still remain empty in the way to obtain the optimum value of the parameters in the environmental simulation models.

This study applied the fuzzy method to define the optimum value in the parameters of the model, such as the wind speed, stability in the Gaussian diffusion model. The main topics in this chapter include the air quality forecasting and decision making method is in the second section. , Framework of fuzzy optimization in decision making of air quality management is described in the third section. Finally, the application of this model is presented in section four.

2 Air Quality Forecasting and Decision Making Method

2.1 Forecasting by Monitoring

To predict future results, using current information to speculate is the most direct way. Especially when the time interval is not far away from now, the best way to do the estimation is the estimation by current situation. As shown in Figure 1, it is the results of an air quality monitoring stations for three consecutive observing days. We can use the results of this three-day observation to speculate one-day, two-day, and three-day or future value. Because the data comes from the actual observation, if all the processes are in line with the necessary procedures, then the data is reliable. So there will be not much controversy of this data. (Liang and Tsai, 1980)(Liang and Chang, 1983)(Chen, 2009)(Yuan et al, 2000a,b)

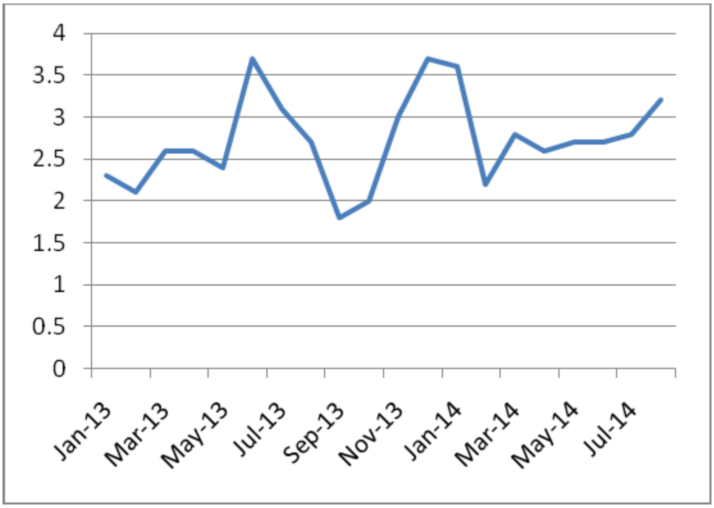


Fig. 1 An example to obtain the data by observation from a monitoring station (Source: Taipei EPD, 2014)

But when the time to speculate is far away from the observation time, say, in the case when the policymakers want to know whether typhoon will happen or not in the time next year? Or the environmental protection authorities now want to know how the air quality in Taipei is in order to decide the possibility to hold large outdoor sports without affecting the participant's health. These data this time has been inadequate clearly. Then we need the help of other ways to get more information for policymakers to analyze.

Another drawback of actual monitoring is that it is unable to simulate different scenarios. For example: the policymakers want to know what possible disasters of petrochemical plants is, when the gas explosion occurs, so as to make an emergency response plan to the local residents after gas explosion. However we cannot create a gas explosion situation for the policymakers to monitor. And most of the monitoring may not be the scenario that policymakers need to know because the situations policymakers want to know are always the situation of extreme condition. The real example such as the Kaohsiung oil pipeline gas explosion incident, Japan's Fukushima nuclear power plant accident events, both are not able to be analyzed by the actual monitoring data from a particular situation we designed and set in advance.(Lipscy et al., 2013)(Chen and Hong, 2014)

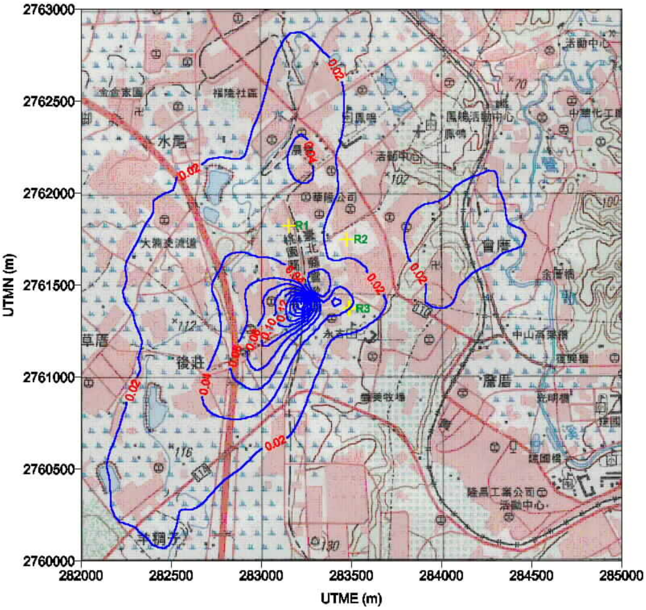
Another economy consideration is the burden from the cost. Monitoring stations usually takes a very high cost, and the information obtained in the monitoring can be used in the current time and space only. Change to other scenarios, then the monitoring information cannot be applied. Therefore, the monitoring result data are usually regarded as a verification and corroboration of decision. For example, if the environmental decision-making officials wondered the effectiveness of air pollution control measures, then they can conduct field monitoring in certain locations at certain times. The results obtained can be used as the verification of control strategy effectiveness. (Goldstein, 1977)

2.2 Forecasting by Model

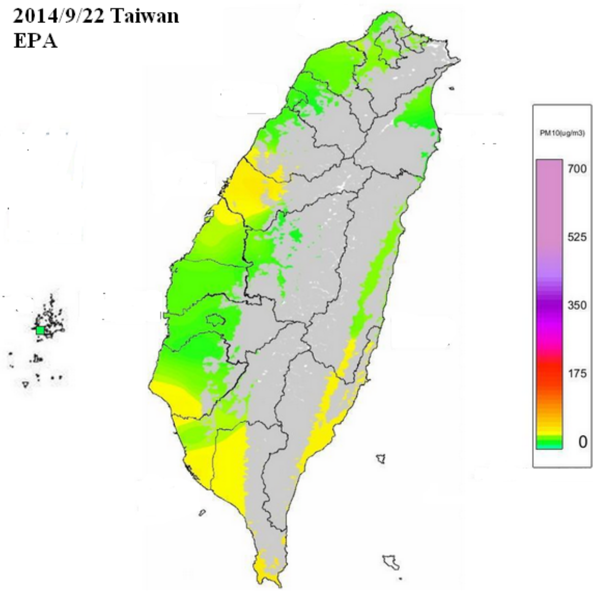
Model provides us with more information than monitoring data, including time and space. For example in Figure 2, that is the distribution of air pollution in Taipei, it provides us with the distribution in each point of contamination on this map. This is what the actual monitoring cannot be done. It can also be obtained of the values in domain of different times. For example, time series analysis model, it can simulate the concentration distribution of the time for period of decision analysis. (Chang and Chang, 2002)(Chen and Wang, 2007)(Chen,2009)(Chen, 2010a,b)(Chen et al., 2008).

Model can be divided into two categories, physical models and mathematical models. The physical condition is to reduce the actual type into the laboratory, and then use the laboratory data backstep to the real field size for evaluation. The example is the water canal experiments in water conservancy engineering and the wind tunnel experiments in aeronautical engineering. (Faunae et al., 1986)(Uehara et al., 2000)(Naidu et al., 2013) Since the model is controlled in a laboratory, so it is possible to create a variety of different scenarios for simulating.

Mathematical model considers the various changes in physical and chemical factors. (Yao and Liu, 2013) If expanded to other areas, it is also possible to include social factors and economic factors. The advantage of mathematical model is that it is able to set a variety of different parameter to make the different contexts. Helping the decision-makers to get a clearer idea and make their decision more explicit. For example, in a mathematical model of socio-economic, the birth rate can be taken into account for considerations, so that the real GDP results can be forecasted. In the chemical reaction, the chemical reaction rate at different temperatures changes can be considered to know what species to be generated finally. In an air pollution dispersion model, It is also possible to include different weather conditions, including wind speed, wind direction, atmospheric stability degree, to know the distribution of air pollution under different scenarios for policy makers.

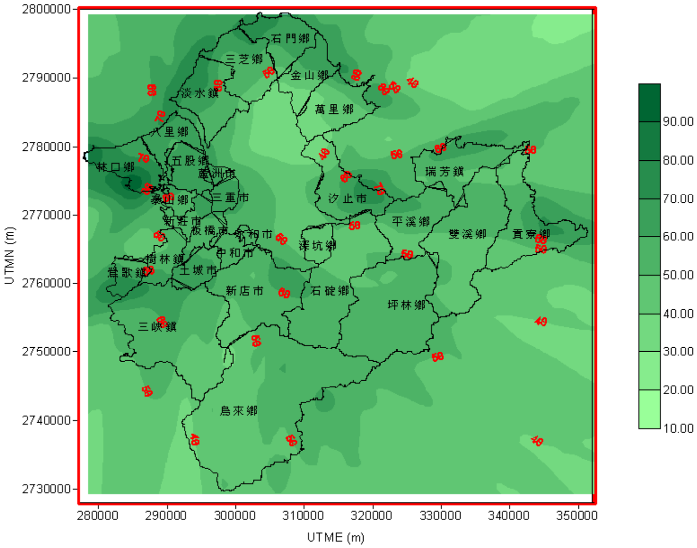


(a) An example for air quality distribution in a city

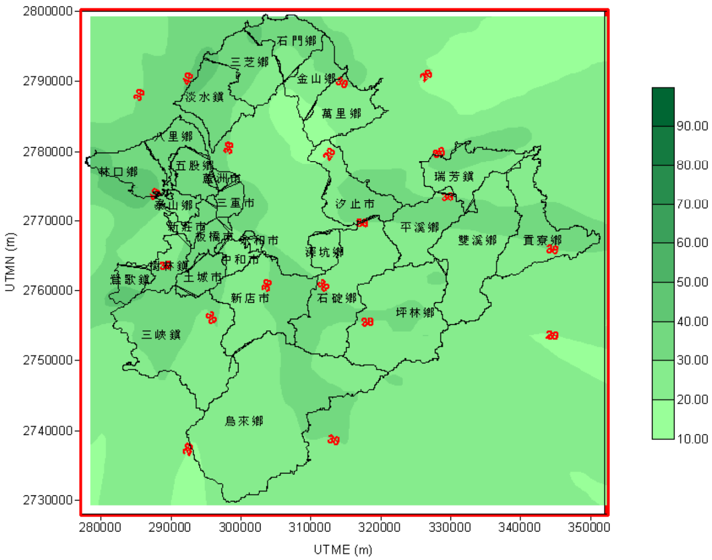


(b) Air quality distribution of Taiwan (Source: Taiwan EPA, 2014)

Fig. 2 Spatial distribution pattern predicted results by air quality model



(c) Air quality map for decision making, the condition before control



(d) Air quality map for decision making, the condition after control

Fig. 2 *(continued)*

However, the results of models are often challenged. The most common challenge comes from the reasonability of model variable settings. Since the model is the simplification of the nature phenomenon, therefore, there are many assumptions in the model. If the assumption is far from the actual situation, then it is not suitable to take into account as a basis for decision-making analysis. But in model the trend of the real situation and the simulated conditions in a particular context is showing clearly. These are the basis for decision making which can offer very effective suggestion decision-makers. So make the best use of the advantages of model is a big help for decision-makers of air quality management.

2.3 Expert Decision Making Process for Air Quality Management

Both of the above analysis provides a lot of help for us. But in the decision-making process, the most important thing is the wisdom of experts from policy makers. So we have to add the experts involving process in decision-making so that experts can be adequately demonstrated their wisdom. The expert usually have different opinions, and these opinions are different, how to integrate these opinion together is the main issue to be considered in this research.

Wisdom of experts from different levels: In the above example, the measured data and model data, although both have advantages and disadvantages, but experts may also have their valuable experience. These valuable resources cannot be observed, and not covered by the parameter among the model. Even more, under certain circumstances, experts' intuitions alone can get a good decision. That is the hidden wisdom of an expert. Make good use of this expert's hidden wisdom can make the quality of decisions more ideal.

Wisdom of experts may come from their intuition, yet it can be derived from their professional judgment. For example, those values setting for the parameters in the model, experts with their research experience can provide good advice to decision-makers. Using their recommended values also tend to get preferable simulation results. It also helps decision analysis for those who make the final decision making. Therefore, this chapter will use the fuzzy theory to derive a method which takes the expert wisdom into the results of model analysis and actual observations. Combine all three, which is the real field observations, model simulations, and expert wisdom to make the best combination, and provide policy-makers to make the best possible decisions. (Green et al., 2007)

2.4 Decision Making Process for Air Quality Management

Knowing the true value of air quality is essential for decision making of air quality management. The air pollutant uniformly distributed in the atmosphere so it is difficult to decide the representative point. Scientist has to find the way to tell the decision makers. Good quality of data help us to know the truth of environmental phenomenon, therefore the methodology to find the optimum predicting results becomes more important.

The information of air quality includes the domain of time and space. To know the detail variation, it is necessary to include time segment and space grid. Measuring by equipment is the most direct method, although the cost is very expensive. Developing the cheapest method of measurement can provide more information although it seems not possible in the near future.

The other way to obtain the air quality information is through the simulation model derived from physical, chemical, and mathematical principle. The model made the assumption according to the real situation, nevertheless there is always a bias to the reality. The simulation model plays an important role in forecasting the air quality because it provide adequate data in both time and space domain.

The concept to combine the two data system, measurement and simulation, is a complex procedure. Advantage of them should be involved so as to obtain the optimum solution. If there is no mistake in the measuring procedure, then the observed results are reliable, even if there is only one or few points in the space or time domain. The simulated results undoubtedly include the systematic errors which come from the theoretical assumption. Thus, the errors can be eliminated through properly adjustment by the observed data.

Using statistical methods to force the numerical model to approach the observed value may cause the deletion of the loss of significant physical meaning in the simulation results, although mathematically meet the requirements of optimization. This is the issue of internal consistency many scholars have repeatedly stressed in the study of objective analysis. This issue has been solved until they get a reasonable solution in the year 1958. Sasaki proposed a theoretical basis to engage objective analysis with the variational principle. It is able to maintain internal consistency of the analysis field in a variety of constraints. This method later was known as numerical variational analysis (NVA), or variational objective analysis, also known as variational optimization analysis. This method is able to combine the dynamic, energy, statistical, or empirical condition into an optimal analysis process In order to analyze the variables in weather or ocean. It provide a reliable basis for decision-making for the purposes of air quality management.

But this method has little progress in the subsequent decade. It is not until 1969, Sasaki (1969, a,b) noted characteristic feature of this method is that the constraint functions and filters. Sasaki (1970) has continuously published three articles, it laid the theoretical foundation variational analysis, and the feasibility of its use in meteorology decision analysis. Later, there are many scholars engaged in the application research of variational analysis and objective analysis. Groll (1975) uses Lewis' (1972) model to analyze the weather in Europe and found using binding conditions can really filter out short wave. Sasaki (1976) use integral condition of energy conservation to control the truncation error generated in the integral calculation of numerical weather prediction. It can avoid the errors formation of short wave and high-frequency.

The reliability of weather forecast is the basis of air quality management decisions. After the variational method can be successfully applied in the case of weather forecast, it can also be used in air quality management. The application of variational optimization method allows the interaction patterns between the model and monitored value have more physical meaning. The weighting factor of parameters in the optimization process can be determined by fuzzy expert decision-making process to make it more representative in the variational analysis.

3 Granular Computing in Air Quality Management

3.1 Interactive and Iterative Fuzzy Optimization Model

This chapter described the methodology of the fuzzy optimization by interactive and iterative method. Theoretical development and its characteristics are presented. The experiment results are also shown in the article. Figure 3 is the research framework of this chapter.

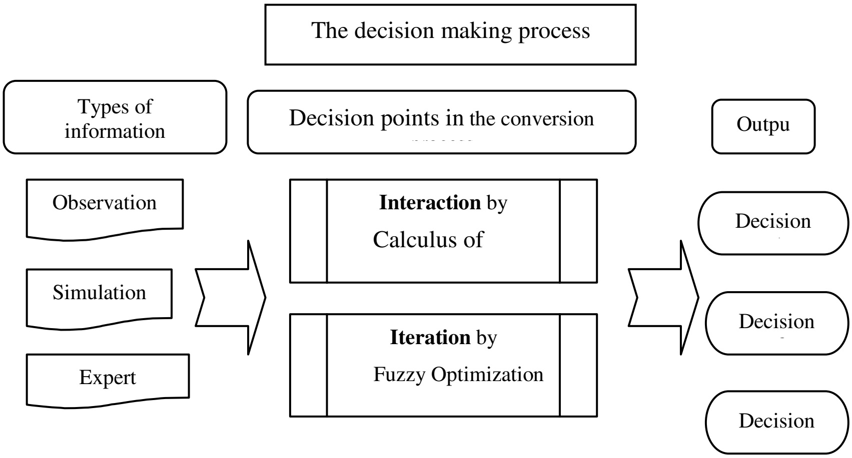


Fig. 3 Framework of fuzzy optimization in decision making of air quality management

Granular computing is the basis of fuzzy decision-making. (Dubois and Prade, 1988) (Goguen, 1967) This chapter also uses the spirits of granular computing to carry out fuzzy decision analysis for air quality management. Assume the experts and human judgment in the fuzzy decision, although very reliable, but it is often based on a lack of clearly and vague. The fuzzy mathematics tries to find a trusted basis from the semantic of expert, although it is often lack of clarity. Zadeh first derived the theoretical equations of fuzzy mathematics.(Zadeh, 1965) (Zadeh, et al. 1996).With his thesis proposed, researchers successor one after another to apply the fuzzy theory to different areas.(Chen, 2010a,b) (Chen and Cheng, 2010)(Yang and Yuan, 2003)(Yuan and Shaw,1995)

3.2 Fuzzy Optimization Method (FOM)

A fuzzy optimization method was developed in this chapter which includes the interactive and iterative stage to obtain the optimum solution of air quality management decision. In the interactive stage, the observed and simulated results are optimized through the fuzzy determination and calculus of variation method. The relative advantage of them can be considered and tuned by the decision makers. In the iterative stage, the optimum value of each parameter in the physical models is determined by the iterative procedure of the invited experts.

This article use calculus of variation to combine and interact between the monitoring data and model results, and take advantage of fuzzy theory to link different expert opinions for the parameters in a model, using fuzzy mathematics to allocate the relative importance of each parameter, and finally obtaining the optimum simulated result.

Because there is a big gap between the different expert opinions, so we reach convergence through iteration process, and provide a clear basis for decision-makers. After each opinion inquiry, repeat the same process for expert's participation, and set minimum threshold of expert opinion which could be tolerated. When the views of the experts reached a minimum requirement of threshold, which is the convergence of expert decisions.

3.3 Mathematical Representation of Interactive Multi-objective Approach

Let$\{ \tilde{c}_m | = 1,2,.....,m \}$represent the observed value of M places, and $\{ \tilde{q}_n | = 1,2,.....,n \}$be the emission amount of N sources. The distributed concentration is a function of Q_n. Assume the concentration in location (x,y) be C(x,y), then

$$C(x,y) = \sum_{n=1}^{N} f_n(x,y) Q_n \tag{1}$$

where f(x,y) is the function determined by the environmental factors such as topography, meteorology, and location, etc.

From the view point of fuzzy theory, the representative of $\tilde{c}_m$ is better than c(x,y) because it is an actual observed data . However, the value of c(x,y) provide more information than $\tilde{c}_m$ because it offers the pattern of the trend in both time and space domain. The other reason to take notice on the value from the simulated model is because the cost of observation is always very expensive. The simulated results could help us to know the phenomenon in case only the limited budget provided.

The uncertainty of simulated value comes from the emission amount of sources and the parameters of diffusion functions, f_n. The ambiguous condition should be treated by the fuzzy theory to obtain the optimum judgments. Thus, the $\acute{\Gamma}_{emi}$, $\acute{\Gamma}_{met}$, and $\acute{\Gamma}_{opt}$ were defined as the parameters which come from the influence of source

Table 1 Main factor affecting the final results of air quality assessment

No.	Symbol	name	description
1	$\acute{\Gamma}_{emi}$	Source emission influence factor	Point, line, area source etc.
2	$\acute{\Gamma}_{met}$	Metrological influence factor	Wind speed, wind direction, mixing height etc
3	$\acute{\Gamma}_{top}$	Topographical influence factor	Elevation, surface roughness etc.

emission, meteorology, and topography. The main factors affecting the final results of air quality assessment value of them are shown in table 1.

Sasaki and Liang proposed the optimization theory to link the observed value and simulated value by the variational technique. First, considering the errors, R_{1m}, between them is

$$\begin{aligned}(R_{1m}) &= C(x_n, y_m) - \tilde{C}_m \\ &= C_m - C_m, m = 1,2,\dots\dots M\end{aligned} \tag{2}$$

where $f_n(x,y)$ is the dispersion function. Since there are M observed value and N source, in order to use the most value of observed information, it is essential to consider the errors from source emission, which means not only C_m close to $\tilde{C}_m$, but also the Q_n has to be close to $\tilde{Q}_m$. Thus

$$(R_2)_n = Q_n - Q_n, n = 1,2,\dots\dots N \tag{3}$$

where $\tilde{Q}_1, \tilde{Q}_2, \dots\dots \tilde{Q}_N$ is the observed value of source emission. The optimum solution exist in the condition of the following

$$\begin{aligned}E &= \sum_{m=1}^{M} (R_1)_m{}^2 + \beta^2 (R_2)_n{}^2 \\ &= \sum_{m=1}^{M} (C_m - \tilde{C}_m)_m{}^2 + \beta^2 (Q_n - \tilde{Q}_n)_n{}^2\end{aligned} \tag{4}$$

where β is the weighting factor determined by the relative importance of these two factors.

If there are more parameters which influence the factor, β, then

$$\beta^2 = \beta_1{}^2 + \beta_2{}^3 + \beta_3{}^2 \tag{5}$$

where β_1 represent the influence of source emission, β_2 represent the influence of meteorology, β_3 represent the influence of topography.

Expanding the above equation, if there are more parameters involved in the simulation model, the general forms of equation becomes

$$\beta^2 = \beta_1{}^2 + \beta_2{}^3 + \beta_3{}^2 + \dots\dots\dots + \beta_\kappa{}^2 \tag{6}$$

where κ is the total number of parameters which exists in the simulation model.

therefore, the optimum value for decision making could obtained when the E value is minimum, thus

$$\delta(E) = 0 \tag{7}$$

3.4 The Interactive Calculation between the Analytical and Observed Data

In case of only one parameter, say source emission, considered in the optimization procedure, then the optimum strength of source should be determined. To obtain the optimum source emission strength, The matrix form of equation is rewritten as the following(Liang, 1979)

$$(F^F + \beta^2 I)\vec{\tilde{Q}} = (F^T \vec{\tilde{C}} + \beta^2 \vec{\tilde{Q}}) \tag{8}$$

Where

$$\vec{Q} = [Q_1, Q_2, \cdots, Q_N]^T,$$
$$\vec{\tilde{C}} = [C_1, C_2, \cdots, C_M]^T,$$
$$\vec{\tilde{Q}} = [Q_1, Q_2, \cdots, Q_N]^T,$$

T is the transformation of matrix, and I is the unit matrix.

The equation (8) become

$$A\vec{Q} = \vec{B}, \tag{9}$$

and

$$A = F^T F + \beta^2 I$$
$$B = F^T \vec{\tilde{C}} + \beta^2 \vec{\tilde{Q}}$$

The optimum emission strength can be determined by the interactive procedure as the following equation

$$\vec{Q} = A^{-1}\vec{B}, \tag{10}$$

The optimum concentration for decision making of air quality management is

$$C(x, y) = \sum_{n=1}^{N} f_n(x, y) Q_n. \tag{11}$$

Liang proposed a Strong Optimization and Weak Optimization method in decision making theory to solve the problem of differences between measured and simulated value, and how to get the best approach by interaction tradeoff. The strong interactive optimization (SINO) requires all the data consistent with the observed results. Thus the sum of errors has the minimum value to make sure all of them are closed to the observed data.

3.5 Mathematical Representation of Iterative Calculation Approach

In this paragraph, Gaussian diffusion equation will be used as an example in the air quality assessment. It is used to describe the method using three variables in the function and obtain the best decision. The best optimization of expert's opinion was obtained by fuzzy optimization method. Commonly used Gaussian diffusion equation is as follows (Stern, 1968)

$$C(x,y,z,H) = \frac{Q}{2\pi U\sigma_X\sigma_Y}\exp\left(-\frac{y^2}{2\sigma_y{}^2}\right)\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_y{}^2}\right]+\exp\left[-\frac{(z+H)^2}{2\sigma_z{}^2}\right]\right\} \tag{11}$$

In the above formula, Q is the amount of emissions, U is the wind speed, in addition, sigma x, y is the diffusion coefficient in the horizontal and vertical direction. Because they are independent of the function, therefore, the above equation can be removed individually, and individually treated by optimization.

Let β_1, β_2, β_3, β_4 represents the influence from emissions, wind speed, atmospheric stability, and diffusion coefficient. Then equation (6) can be written as

β^2= (source variation) + (wind speed variation) + (stability variation) + (diffusivity variation)

$$= \beta_{\text{source}}{}^2+\beta_{\text{meteorology}}{}^2+\beta_{\text{stability}}{}^2+\beta_{\text{diffusivity}}{}^2$$

$$= \beta_1{}^2+\beta_2{}^2+\beta_3{}^2+\beta_4{}^2 \tag{12}$$

When individually consider of their impact, the above equation can be rewritten as

$$C(x,y) = \sum_{n=1}^{N} Q_n . f_{Q_n}(x,y). \tag{13}$$

$$C(x,y) = \sum_{n=1}^{N} U_n . f_{U_n}(x,y). \tag{14}$$

$$C(x,y) = \sum_{n=1}^{N} S_n . f_{S_n}(x,y). \tag{15}$$

$$C(x,y) = \sum_{n=1}^{N} \mathrm{K}_n . f_{K_n}(x,y). \tag{16}$$

Q_n, U_n,S_n, K_n, Q_n, U_n, S_n, and K_n in formula (13), (14), (15), (16) respectively represent the errors from the pollution emissions, wind speed, atmospheric stability, and diffusion coefficient. Qn, Un, Sn, Kn, these four key variables are part of Gaussian dispersion function, therefore, it is possible to obtain the optimized emission amount, wind speed, atmospheric stability, and diffusion coefficient.

$$C(x, y) = \sum_{n=1}^{N} Q_n . f_{Q_n}(x, y). \tag{17}$$

$$C(x, y) = \sum_{n=1}^{N} U_n . f_{U n}(x, y). \tag{18}$$

$$C(x, y) = \sum_{n=1}^{N} S_n . f_{S n}(x, y). \tag{19}$$

$$C(x, y) = \sum_{n=1}^{N} \mathrm{K}_n . f_{K n}(x, y). \tag{20}$$

3.6 Iterative Calculation from Different Decision Maker

The determination of an environmental condition can be judged by a group of expert through the fuzzy optimization procedure. The procedure is an iterative process to obtain the optimum results among a group of experts. In the beginning, the opinion from these experts is not the same, so the second time choose the most closed results and re-run the procedure. After a certain runs, the opinion comes to consistent. (Rowe and Wright, 2001) (Green et al, 2007) (Tapio, 2003)

If the iteration among the experts is very strong, then it is called "Strong Interactive Optimization (SITO), which means the results comes from the common idea of all the experts is high. The SITO method requires the results from the experts be very close. If the iteration among the experts is few, then it is called "Weakly Interactive Optimization (WITO), which means the results comes from the common idea of all the experts is low. The extent of these parameters should be determined by the expert through a fuzzy determination process as list in table 2.

Table 2 The fuzzy representation of the main parameters affecting the simulated results

type	Extremely low	very low	low	slight low	medium	slightly high	strong	very high	extremely high
symbol	A	B	C	D	E	F	G	H	I
number	1	2	3	4	5	6	7	8	9
Percent	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

The above values are determined by the experts of decision makers for further analysis. The decision makers can decide the value by the objective determination based on their understanding. (Rescher, 1998)

Delphi method was used in this study to make the expert advice to achieve convergence condition. (Michael et al.,1996)Delphi method, also known as an expert investigation, is a way of consultation using the communication method with experts. It requires the experts to solve the problem alone by the questionnaires, and summarizes the views of all the experts and recovered, then sorting out a comprehensive advice. (Harold et al., 2002)) Subsequently the comprehensive advice and prediction problems then were back to the experts, consultation with the experts once again. So many times of iteration over and over again, And gradually obtain more consistent approach to the decision making predictions. (Rowe and Wright,1999) (Basu, et al.,1977) (Dalkey, and Helmer ,1963)

The optimum value of the parameters applied in the model depends on the opinion expert from different view point. Thus an iteration procedure to obtain the optimum value is required. Procedure for determining the value is as the following. (Harold et.al,1975) (Adler and Ziglio,1996)

(1) Form a group of experts. Identify experts in accordance with the required knowledge of the subject. The number of experts is according to the subject size, Usually it is no more than 20 people.
(2) Raise the issue to be predicted and the requirements to all the experts, attach all the background material on the subject, and also requested experts what is the required material. Then, make a written reply from the experts.
(3) Each expert make their forecast opinions according to the material they received, and explain how they use these materials to make the suggested value.
(4) Make a summary of the views of the first time judgment of experts, tabulated chart are compared, then circulated to the experts again. Let the experts compare themselves with others of different opinions, Modify their opinions and judgments. Is also possible to collate the views of the experts, requested higher status or other experts to comment, then put these views again distributed to the experts so that they can modify their own views for reference.
(5) Collect the modified views of all the experts, summarize, and once again circulated to all the experts in order to make the second revision. By-round collection of advice and feedback expert information is the main part of Delphi method. Collect comments and feedback generally through three or four round. In time feedback to the experts, only give various opinions, but does not indicate the specific names of all opinions of experts. This process is repeated until each expert does not change views.
(6) Comprehensive handle on expert advice.

The opinion among the experts is very different. However, the final decision still necessary, therefore, the results is the aggregate solution of all these experts, as shown in the following figure.

4 Application of FOM in Air Quality Management

4.1 Comparison of Model Output Results and Field Monitoring Results

Figure 4 is the result obtained by monitored data. Because it is impossible to obtain the monitoring value in each grid point, so it is using the information of different monitoring stations and curve drawing program to get the final concentration.

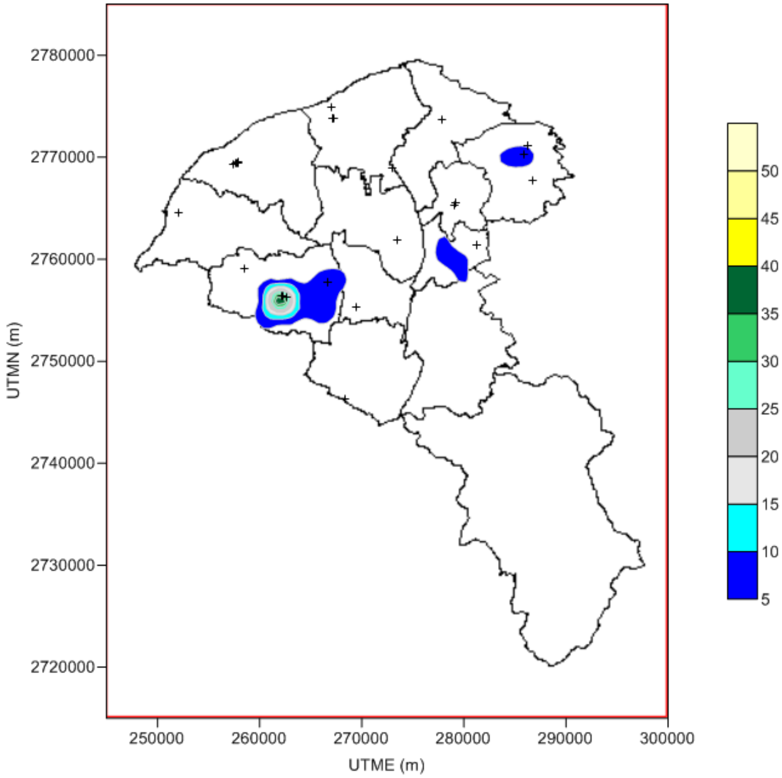


Fig. 4 Air pollution distribution using the interpolate data of monitoring station

The monitoring results provide us the concentration in the exact point. On the other hand, Gaussian modes can obtain the different concentrations distribution at respective grid points. This is a mathematical model with analytical solution. We can also use different numerical models to get similar distribution pattern.

4.2 Influences of Interactive Fuzzy Optimum Method

The results from the simulated results have much useful information. In some condition, it is not necessary to force the data to consistent with the observed data. This situation could be regarded as the "weak interactive optimization (WINO), which means the interaction between the observed data and simulated data is very weak. The air quality model is a Gaussian type air quality model, and there are five stations in this study, if all the results are fitted by the stations, then the results may lost its physical meaning, just because of the purpose to fit the measured data.

Table 3 Determine the relative importance weighting by iteration method among the experts

No. of expert	First round			Second round			Third round		
Parameters in the model	β_1	β_2	β_3	β_1	β_2	β_3	β_1	β_2	β_3
A	0.7	0.2	0.1	0.75	0.2	0.05	0.67	0.25	0.09
B	0.6	0.3	0.1	0.65	0.25	0.1	0.70	0.20	0.10
C	0.8	0.1	0.1	0.75	0.1	0.15	0.69	0.10	0.21
D	0.6	0.2	0.2	0.72	0.1	0.18	0.70	0.11	0.19
E	0.4	0.4	0.2	0.55	0.35	0.1	0.58	0.32	0.10
F	0.55	0.4	0.05	0.65	0.3	0.05	0.65	0.30	0.05
G	0.7	0.25	0.05	0.72	0.23	0.05	0.70	0.2	0.1
Average	0.6214	0.2642	0.1142	0.6842	0.2185	0.0971	0.67	0.2114	0.12

Because the SINO forced the simulated value to be equal to the value of monitoring station, so it has to adjust the value of diffusion equation in emissions or other parameters. It may result in the circumstances of negative emissions, or the wind speed is less than 0. This method provides a mechanism for policy makers to decide the weighting by themselves. The results of strong iterative optimization are shown in figure (a) in this figure. Apart from the previous researches which only apply the monitored data and simulated results to decide the optimum value, our method includes the expert opinion the uncertainty of parameter value. So it reserves the physical meaning of the model and offer a more reasonable explanation of our decision.

4.3 Influences of Iterative Fuzzy Optimum Method

The optimum value for decision from different decision makers is usually not the same. In order to get the optimum values in line with the physical significance. it is suggested to determine the best value beta with experts iteration.

Which is the optimum value of the different parameters can be obtained by the fuzzy decision procedure. In this model, for example, after expert discussions, the set of weights were 0.2,0.3,0.4,and 0.1。

4.4 Experimental Outcome of Fuzzy Optimum Model

Take the information of Figure 4 as the basis and applying the fuzzy optimization method to obtain the results of figure 5. This result is in line with the actual monitoring data obtained after correction interaction.

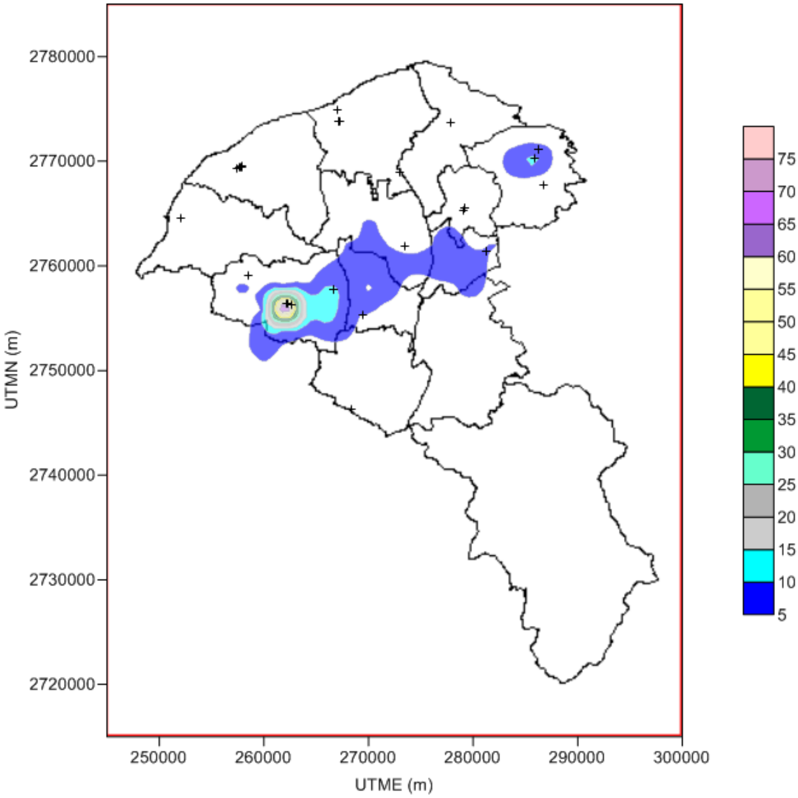


Fig. 5 Results of air pollution distribution using interactive correction between actual value and monitored values

4.5 Limitations and Future Research Needs

In this study, the fuzzy variational optimization theory was deduced and applied in the simulation of an air quality management. From preliminary results it seems this method can really be used in the decision making process of air quality management. Not only the value can be verified by the actual observations, but also keep the physical meaning in the air quality dispersion model. The results of air quality diffusion model after the handle of variational optimization method still can clearly describe the behavior of air pollutant dispersion. Therefore, the conclusions of policy become more reliable.

Owing to the limit time and resource, this research cannot provide more detail results of various parameters. The future study should focus on the different parameters' characteristic such as the wind speed, temperature, and diffusion coefficient etc.

5 Conclusions

This chapter has described an optimization model for decision making in air quality management which can combine the observed value and simulated output. The variational calculus was used to maintain the physical meaning of the model. The optimized value of the parameters in the physical model was determined by the fuzzy expert decision method.

The optimization method gives the mathematical representation to find the equilibrium point. Yet, how to obtain and express these optimal data depends on the fuzzy optimization techniques. The methodology and algorithm of fuzzy decision making process by interactive multi-objective approach and iterative optimization method are described, with the application in the process of air quality management.

A numerical experiment was presented in this chapter, a physical diffusion model was used to calculate the air pollutant concentration, and then some variational equations were derived. Then the calculated results were corrected by the monitored data with the variation calculus. The experts determine the weighting factor of each parameter. Therefore, the final decision was determined by the interactive process between the simulated and monitored results. The combined approach of interactive and iterative method for fuzzy optimization model makes the decision of air quality management more accurate and pragmatic.

References

1. Adler, M., Ziglio, E. (eds.) Gazing Into the Oracle: The Delphi Method and Its Application to Social Policy and Public Health. Kingsley Publishers, London (1996) ISBN 978-1-85302-104-6
2. Basu, S., Schroeder, R.G.: Incorporating Judgments in Sales Forecasts: Application of the Delphi Method at American Hoist & Derrick. Interfaces 7(3), 18–27 (1977), doi:10.1287/inte.7.3.18
3. Chang, D.C., Chang, Y.C.: Application of fuzzy cluster algorithms in pollutant's spatial distribution of Kaohsiung coast. Master thesis, National Sun-Yat Sen University, Kaohsiung, Taiwan (2002)

4. Chen, W.K.: Study of the Pattern Recognition of Particulate Concentration by Fuzzy Time Series and Neural Network Analysis. Paper presented at the 2009 Cross Strait Conference on Aerosol Science and Technology (2009)
5. Chen, W.K.: An Approach to Pattern Recognition by Fuzzy Category and Neural Network simulation. Paper presented at the 2010 International Conference on Machine Learning and Cybernetics, ICMLC (2010a)
6. Chen, W.-K.: Environmental applications of granular computing and intelligent systems. In: Pedrycz, W., Chen, S.-M. (eds.) Granular Computing and Intelligent Systems. ISRL, vol. 13, pp. 275–301. Springer, Heidelberg (2011b)
7. Chen, W.K., Wang, P.: Numerical Modeling of Gas-phase Kinetics in Formation of Secondary Aerosol. China Particuology 5(4), 267–273 (2007), doi:10.1016/j.cpart.2007.05.002
8. Chen, W.K., Cheng, C.S.: Application of Grey Theory in Predicting the Disaster Loss of Typhoon. In: 2012 Global Chinese Conference on Environment and Energy, Hsinchu, Taiwan (2012)
9. Chen, W.K., Hong, Y.H.: Causal Analysis of Kaohsiung Gas Explosion Incident by Event History Method. In: Sustainable 2014 Development and Environmental Conference, Chungli, Taiwan (2014)
10. Chen, W.K., Lin, C.C., Yu, C.H.: Establishment of the Pollution Simulation and Particulate Control Technology to the Exposed Surface Area–An Assessment Techniques Combining the Satellite Image Interpretation and Air Quality Models. Journal of Environmental Protection 31 (2008)
11. Dalkey, N., Helmer, O.: An Experimental Application of the Delphi Method to the use of experts. Management Science 9(3), 458–467 (1963)
12. Dubois, D., Prade, H.: Fuzzy Sets and Systems. Academic Press, New York (1988)
13. Fraunie, P., Beguier, C., Parachivoiu, I., Brochier, G.: Water channel experiments of dynamic stall on Darrieus wind turbine blades. Journal of Propulsion and Power 2(5), 445–449 (1986), doi:10.2514/3.22927(1986)
14. Goguen, J.A.: L-fuzzy sets. Journal of Mathematical Analysis and Applications 18, 145–174 (1967)
15. Goldstein, I.F., Landoritz, I.: Analysis of Air Pollution Patterns in New York City. I. Can on station represent the Large Metropolitan Area? II. Can one Aerometric Station Represent the Area Surrounding it? Atmos. Envir. 11, 47–57 (1977)
16. Green, K.C., Armstrong, J.S., Graefe, A.: Methods to elicit forecasts from groups: Delphi and prediction markets compared. Foresight: The International Journal of Applied Forecasting 8, 17–20 (2007)
17. Gustafson, S.A., Kortanek, K.O., Sweigart, J.R.: Numerical Optimization Techniques in Quality Modeling: Objective Interpolation Formulus for the Spatial Distribution of Pollution Concentration. J. Appl. Meteor. 16, 1243–1255 (1977)
18. Linstone, H.A., Torof, M.: The Delphi Method: Techniques and Applications. Addison-Wesley, Reading (1975) ISBN 978-0-201-04294-8
19. Linstone, H.A., Torof, M. (eds.) The Delphi Method:Techniques and Applications, Murray Turoff and Harold Linstone, TOC III.B.3. The National Drug-Abuse Policy Delphi: Progress Report and Findings to Date, IRENE ANNE JILLSON (2002), http://is.njit.edu/pubs/delphibook/ch3b3.html

20. Heimbach, J.A., Sasaki, Y.: A Variational Technique for Mesoscale Objective Analysis of Air Pollution. J. Appl. Meteor. 16, 1243–1255 (1977)
21. Liang, W.J.: The Optimization theory of Air Pollution Assessment Annual Report of the Institute of Physics. Academia Sinica 9 (1979)
22. Liang, W.J., Lee, C.T.: Optimization Assessment of Sulfur Dioxide Pollution and Monitoring Network in Kaohsiung Area. Journal of the Chinese Institute of Engineers 3(2), 105–115 (1980)
23. Liang, W.J., Lee, K.T.: Optimization Assessment of Carbon Monoxide Pollution and Monitoring Network in Taipei City. Journal of the Chinese Society of Mechanical Engineers 1(1) (1980)
24. Liang, W.J., Tsai, F.C.: Research on the Time Series Model for Prediction of the Sulfur Dioxide Pollution in Taipei City. Annual Report of the Institute of Physics, Academia Sinica 10 (1979)
25. Liang, W.J., Young, P.H.: Theory and Application of the Aggregate and Average Optimization in Air Pollution Assessment. Annual Report of the Institute of Physics, Academia Sinica 10 (1980)
26. Liang, W.J., Hsieh, C.S.: Objective Analysis of the Finite Element Method. Annual Report of the Institute of Physics, Academia Sinica 10 (1980)
27. Liang, W.J.: The Variational Optimization of Wind Field for the Estimation of Vertical Velocity. Proc. Natl. Sci. Counc. ROC. 4(3), 249–259 (1980)
28. Liang, W.J., Chen, W.K.: Application of Model Output Statistics in Air Quality Assessment. Annual Report of the Institute of Physics, Academia Sinica 11 (1981)
29. Liang, W.J., Chang, R.T.: Study on the Time Series Model for the Parameters in Atmospheric Diffusion Model. Annual Report of the Institute of Physics, Academia Sinica 13, 1979 (1983)
30. Lipscy, P.Y., Kushida, K.E., Incerti, T.: The Fukushima Disaster and Japan's Nuclear Plant Vulnerability in Comparative Perspective. Environmental Science & Technology dx.doi.org/10.1021/es4004813 | Environ. Sci. Technol. 47, 6082–6088 (2013)
31. Turoff, M.: The Design of a Policy Delphi. Technological Forecasting and Social Change 2, 2 (1970)
32. Naidu, M.K., Tian, Z.F., Medwell, P.R., Birzer, C.H.: An Investigation of Cool Roofing on Urban Street Canyon Air Quality. In: 20th International Congress on Modelling and Simulation, Adelaide, Australia, December 1-6 (2013), `http://www.mssanz.org.au/modsim`
33. Novák, V.: Are fuzzy sets a reasonable tool for modeling vague phenomena? Fuzzy Sets and System 156, 341–348 (2005)
34. Rescher: Predicting the Future. State University of New York Press, Albany (1998)
35. Rowe, Wright: The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting 15(4) (October 1999)
36. Rowe, Wright: Expert Opinions in Forecasting. Role of the Delphi Technique. In: Armstrong (ed.) Principles of Forecasting: A Handbook of Researchers and Practitioners. Kluwer Academic Publishers, Boston (2001)
37. Sasaki, Y.: Proposed inclusion of time variation terms, observed theoretical, in numerical variational objective analysis. J. Meteor. Soc., 115–124 (1969)

38. Sasaki, Y.: Some basic formalisms in numerical variational analysis. Mon. Wea. Rev. 98, 875–883 (1970a)
39. Sasaki, Y.: Numerical variational analysis formulated under the determined by long wave equations and a low pass fielter. Mon. Wea. Rev. 884–898 (1970b)
40. Sasaki, Y.: Numerical variational analysis with weak constraints to surface analysis of severe storm gust. Mon. Wea. Rev. 98, 89 (1970c)
41. Sasaki, Y.: Variational design of finite difference scheme for problem of an integral constraints. J. Comp. Phy. 278, 21–270 (1976)
42. Stern, A.C.: Air Pollution, pp. 425–463. Academic Press, New York (1968)
43. Tapio, P.: Disaggregative Policy Delphi: Using cluster analysis as a tool for systematic scenario formation. Technological Forecasting and Social Change 70(1), 83–101 (2003), http://dx.doi.org/10.1016/S0040-1625(01)00177-9
44. Taipei Environmental Protection Department, Historical Air Quality data of Taipei City (2014), http://www.tldep.taipei.gov.tw/C_INDEX/ENVIR/air_5.asp
45. Taiwan Environmental Protection Administration, Historical Air Quality data of Taiwan (2014), http://taqm.epa.gov.tw/taqm/zh-tw/YearlyDataDownload.aspx
46. Uehara, K., Murakami, S., Oikawa, S., Wakamatsu, S.: Wind tunnel experiments on how thermal stratification affects flow in and above urban treet canyons. Atmospheric Environment, volume 34, Issue 10 2000, 1553–1562 (2000), doi:10.1016/S1352-2310(99)00410-0
47. Yang, H.Y., Yuan, C.S.: The correlation of the visibility variation with weather patterns and meteorological factors in the south of Taiwan. In: 96th AW&MA Annual Meeting, San Dieago, California (June 2003)
48. Yao, J., Liu, W.: Nonlinear Time Series Prediction of Atmospheric Visibility in Shanghai. In: Pedrycz, W., Chen, S.-M. (eds.) Time Series Analysis, Model. & Applications. ISRL, vol. 47, pp. 385–399. Springer, Heidelberg (2013)
49. Yuan, C.S., Lee, C.G., Chang, J.C., Liu, S.H., Yuan, C., Yang, H.Y.: Correlation of Atmospheric Visibility with Chemical Composition and Size Distribution of Aerosol Particles in Urban Area. In: 93rd Air and Waste Management Association Annual Meeting, Salt Lake City, Utah (June 2000a)
50. Yuan, C.S., Lee, C.G., Liu, S.H., Chang, F.T.: Innovative Measurement of Visual Air Quality and Its Correlation with Meteorological Factors and Air Pollutants in Subtropics. presented at Seventh International Conference on Atmospheric Sciences and Applications to Air Quality and Exhibition, Taipei (November 2000b)
51. Yuan, Y., Shaw, M.J.: I nduction of fuzzy decision trees. Fuzzy Sets and Systems, 125–139 (1995)
52. Zadeh, L.A.: Fuzzy sets. Information and Control 8(3), 338–353 (1965)
53. Zadeh, L.A., et al.: Fuzzy Sets, Fuzzy Logic, Fuzzy Systems. World Scientific Press (1996) ISBN 981-02-2421-4