# 行政院國家科學委員會補助專題研究計畫成果報告

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## ※　　工業區 SOx 監測站網多目標規劃分析　　※

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計畫編號：NSC 90－2211－E－009－020
執行期間： 90 年 08 月 01 日至 91 年 07 月 31 日

計畫主持人： 高正忠
研究助理: 謝銘儒
共同主持人：

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執行單位：國立交通大學環境工程研究所

中　華　民　國　91　年　09　月　20　日

# 行政院國家科學委員會專題研究計畫成果報告

## 工業區 SOx 監測站網多目標規劃分析

## Multiobjective Analysis for Industrial DISTRICT Air Quality Monitoring Network

計畫編號：NSC 90－2211－E－009－020
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### 一、中文摘要

工業區內高污染性工業對於鄰近地區空氣品質會造成潛在的環境影響，因而有必要設置適當地空氣品質監測站網，以瞭解工業區鄰近地區空氣品質時空變化情形及評估防治措施之成效。唯監測站網位置適當與否會影響監測的代表性及成本效益。本研究探討以多目標規劃適當地工業區空氣品質監測站網，以期能令站網具備代表性及符合多目標的評選標準。本研究以一個工業區案例，應用 ISC3 模擬案例區內污染物濃度之時空變化。根據模式所產生一整年濃度時空變化資料及偵測頻率最高、偵測累積濃度最大、受工業區外污染源影響最小、監測站網總偵測面積最大、保護人口最多等五項目標探討在不同目標考量下所得站數及站址與掌握污染物時空代表性，並比較及討論結果之差異性，以期在考量多目標下，能決定適當的站網分佈。

關鍵詞：監測站網、多目標規劃、環境系統分析

### Abstract

An industrial district with polluting factories operating inside poses a potential threat to the air quality of the surrounding areas. Establishment of a proper air quality monitoring network (AQMN) is therefore necessary for evaluating the temporal and spatial variation of air quality in the vicinity of an industrial district and assessing the effectiveness of pollution control facilities and strategies. The layout of the AQMN should be adequate to assure the quality of monitored data. Monitoring stations located at inappropriate sites may greatly affect data validity and cost effectiveness. A multiobjective approach was explored for configuring an AQMN for an industrial district and a case study was implemented. A dispersion model was used to simulate hourly pollutant concentration distribution in the study area. According to the simulated results and optimization models established based on five objectives of maximum detection, maximum dosage, minimal influence from pollutant sources outside of the district, maximum coverage, and maximum population protection, AQMNs with varied numbers of stations and spatial distribution were obtained. The AQMNs were evaluated for their effectiveness for monitoring the temporal and spatial variation of pollutants. The difference among the AQMNs were discussed. The multiobjective analysis is expected to facilitate the decision making for an appropriate AQMN.

**Keywords**: monitoring network; multiobjective programming; environmental systems analysis.

### 二、緣由與目的

Air pollutions emitted from factories in an industrial district are potentially hazardous to the surrounding environment. These pollutants affect human health, materials, agriculture, forestry, etc. For ensuring the health of residents and a clean living environment in the vicinity of an industrial district, it is important to establish a proper AQMN to evaluate the spatial and temporal distribution of pollutants and the effectiveness of control facilities and strategies.

A good AQMN depends primarily on the suitability of monitoring sites. Improper sites are unable to effectively grasp the characteristics of pollution. Monitoring site planning was generally done based on empirical judgment or simple qualitative rules, such as distance to neighboring residential areas, although several systematic approaches were available [2][6][7][8]. The majority of past studies considered only a single objective, but such a design might not be appropriate if other objectives were taken into account. For example, if only maximum detection of air quality standard violations was used as the design objective, the monitoring stations might end up being located at the leeward of the prevailing wind direction, thus unable to grasp the spatial and temporal variations of emitted pollutants. More monitoring sites can enlarge the detection coverage area, but it will increase the total cost. In addition, a proper AQMN for an industrial district should subject to minimum influence of pollution sources outside the industrial district. Therefore, the planning of an AQMN should be better analyzed by a multiobjective model.

Previous multiobjective studies of AQMN, although consider multiple objectives in their models, are not directly applicable for AQMN planning for an industrial district. In the multiobjective mixed-integer programming model proposed in this study, in addition to cost, five objectives are considered: (1) maximum detection capability of pollution potential; (2) maximum dosage detection capability; (3) minimum influence from outside sources; (4) maximum detection area; and (5) maximum population protection.

Given that wind speed and directions vary with time, these uncertainties were also taken into account. This study used USEPA ISCST3 [9] model to simulate distribution of pollutants under hourly wind fields for a whole year to assess the uncertainty in pollutant distribution brought by wind speed and direction variation. Based on the results obtained from the simulation model and the multiobjective models established, the study proceeded to compare the effects of different objectives on the selection of monitoring sites in a case study, in the hope to devise a suitable monitoring network and demonstrate the applicability of the established model.

## 三、多目標模式

In the following description, the potential zone, detection coverage areas, and meteorological uncertainty are explained first, followed by the description of the proposed model, including the objective formulations and relevant constraints.

### *Potential zone*

A monitoring site is generally placed at a location that can best grasp the distribution of pollution. Noll [8] pointed out that a monitoring station should be located in the potential zone and defined the zone with concentration larger than 90% of the maximum. However, the maximum concentration of a plume might be excessively high and 90% of it to define the potential zone might exclude some potential areas and thus might end up missing the alarm signals and failing to catch areas of deterioration in time.

### *Detection coverage areas*

According to the method proposed by Modak [5], the detection area covered by a monitoring site can be determined by the Spatial Correlation Analysis (SCA). SCA is based on the pollution correlation coefficient between a monitoring site and a covered location. If the correlation coefficient is higher than a pre-defined cut-off value, the location is regarded correlated and is covered. This method was also applied by Liu [4], Langstaff [3], and Arbeloa [1] to determine effective coverage areas.

### *Meteorological uncertainty*

Wind speed and wind direction are meteorological factors of greater variations. The distribution of pollutants in the atmosphere varies under different meteorological conditions. This study employed the whole-year hourly meteorological and wind field data for simulation and assessed the efficiency of the planned monitoring network based on simulation results, in the hope that the monitoring network could factor in the variable meteorological conditions.

### *Models*

The multiobjective model in this study was established based on five objectives. The definitions of these objectives and how the relevant models are established are described below.

### *Maximum Detection capability (DC)*

$$\text{Max} \quad o_{DC} = \sum_{i=1}^{I} d_i$$

*S.t.*

$$d_i \le \sum_{j \in M_i} y_j \quad \forall i$$

$$0 \le d_i \le 1 \qquad \text{i=1,…,I}$$

$$\sum_{j=1}^{J} y_j \le Q$$

$$y_j = (0,1) \qquad \text{j=1,}\cdots\text{,J}$$

where $d_i$ is the variable that indicates whether plume *i* is detected; $y_j$ is a (0, 1) integer that indicates whether a monitoring site is set up in grid *j*; $M_i$ the set of grids in plume *i* with pollutant level greater than 100ppb, *I* represents the total number of plumes, *J* is the number of total grids for possible candidate sites; and *Q* is the limit on the number of monitoring sites in an AQMN.

### *Maximum Dosage Detection Capability (DDC).*

$$\text{Max} \quad o_{DDC} = \sum_{j=1}^{J} \left( \sum_{i=1}^{I} C_{ij} \right) * y_j$$

S.T.

The last two constraints of the DC model.

where $C_{ij}$ is the pollutant level at grid *j* of plume *i*.

### *Minimum Effect from Outside Sources (EOS)*

There are considerable sources of pollution outside the industrial district in the study area. An appropriate AQMN for an industrial district should minimize the effect of these outside sources. Thus the following objective formulation was adopted:

$$\text{Min} \quad o_{EOS1} = \sum_{j=1}^{J} \left( \sum_{i=1}^{I} OC_{ij} \right) * y_j$$

S.T.

The last two constraints of the DC model.

where $OC_{ij}$ is the pollutant level at grid *j* in plume i when only outside sources were taken into account.

Given that placing a monitoring site at a grid with low exposure from sources does not mean the site can detect pollution from sources inside the industrial district, the study therefore proposed the following further modification:

$$\text{Min} \quad o_{EOS2} = \sum_{j=1}^{J}\left(\sum_{i=1}^{I}\frac{OC_{ij}}{IC_{ij}}\right) * y_j$$

S.T.

The last two constraints of the DC model.

where $IC_{ij}$ is the pollutant level at grid *j* in plume *i* where only inside sources were considered.

*Maximum Detection Area (DA)*

The total detection area can be defined as follows.

$$a_1 \cup a_2 \cup \cdots \cup a_j \cup \cdots \cup a_Q$$

where $a_j$ is the detection area of respective site, which was defined by the SCA [5] method. When the detection areas of monitoring sites do not overlap, the total detection area will be greater. The model established based on this objective is presented as follows:

$$\text{Max} \quad o_{DA} = \sum_{j=1}^{J} t_j$$

*S.t*

$$t_j \le \sum_{j \in N_j} y_j$$

$$0 \le t_j \le 1 \quad \text{j=1,…,J}$$

The last two constraints of the DC model.

where $N_j$ is the set of grids in which the detection area of each such grid, if a monitoring site is established at the grid, can cover grid *j*, $t_j$ is the variable that indicates whether grid *j* is covered.

*Maximum Population Protection.*

$$\text{Max} \; o_{PP} = \sum_{j=1}^{J} P_j * y_j$$

S.T.

Same constraints with the last two of DC model.

where $P_j$ is the total population within grid *j*.

*Multiobjective model*

Of the five objective models described above, the first and the second ones can be independently applied. A general multiobjective formulation for all objectives is expressed below.

$$Max \quad W_{DC}o_{DC} + W_{DDC}o_{DDC} - W_{EOS}o_{EOS} + W_{DA}o_{DA} + W_{PP}o_{PP}$$

where $W_{DC}$，$W_{DDC}$，$W_{EOS}$，$W_{DA}$及$W_{PP}$ are the respective weights of the five objectives. The multiobjective model is expected to improve the deficiency of considering only the first or second objective. In the following section, the multiobjective model with varied weight sets is applied in a case study for planning an AQMN for a local industrial district. Results obtained with varied weight sets are analyzed and compared.

This study targeted Toufen Industrial Zone in Miaoli County. It was originally planned as a petrochemical industrial zone with an area of 95.1471 hectares. Based on the simulation results using ISCST model [9], locations having the highest concentrations were situated mostly in 5km radius of the industrial zone. There are a total of 58 major sources within the study area which accounted for more than 90% of the total emission. This study tackled the subject based on two scenarios. Scenario I aimed to explore the possible distribution of monitoring sites under the current status of source distribution. Scenario II took into account only the sources inside the industrial zone with the aim to explore the planning of sites when sources were converged inside the zone.

## 四、結果與討論

*Constant cut-off value and varied single objective*

When DC or DDC was the main objective in scenario I, the sites were distributed in the southern part of the industrial zone for the prevailing north wind and northeast wind in the region disperse the majority of pollutants towards the south. But there was a slight difference between the results from DC or DDC. Such result could be attributed to the fact that some grids had high frequency of passing the threshold, but the cumulative dosage might not be high, while some grids did not have too many pollutant level passing the threshold, but they were exposed to relatively high dosage. When the sites were planned based on the objective of DA, the cut-off value was determined mainly by numerical correlation, which might not be related to the level of concentration; in high-concentration area, the coefficient of correlation might be low due to great variations, resulting in smaller maximum detection area in high-concentration area. These findings indicate that DA should not be considered alone, but with DC or DDC at the same time. In Scenario II, only the sources within the industrial zone were considered. Solutions derived from different objectives as discussed above were similar to those in Scenario I. The results also show considering this objective together with DC or DDC is more pertinent, instead of alone.

*Constant cut-off value, varied number of monitoring sites*

When there were fewer sites, generally the optimal one would be selected from the candidates for each addition of site. Such greedy characteristic was primarily why Modak [5] and Arbeloa [1] employed the Minimum Spanning Tree method. But as the number of monitoring sites increased, such characteristics is no longer applicable.

*Varied cut-off values, single objective*

The variation of cut-off value affects mainly the size of detection area of the site. As detection area changes, the size of population protection and site distribution will be affected. Thus the variation of cut-off value will affect mainly the results obtained under the objectives of DA and PP, but not the results of DC and DDC. And simulated results indicate that DC or DDC be factored in as well.

*Multiobjective results*

This study employed NISE method to examine the trade-off relationship between two objectives. Several sets of weights were randomly defined. These weight sets were substituted into the multiobjective model to seek solutions. To make sure that the monitoring network can grasp the background concentration of pollutants, and serves the functions of population protection, the following two provisos were added into the multiobjective model:

1. There will be at least one site at a densely populated area.
2. There will be at least one site at the background (or windward).

As influenced by the first two objectives, sites would fall at the leeward of the sources (main pollution receiving area) as the number of site increased. The solutions derived were similar under cut-off value of 0.9 and 0.8, but show significant difference under cut-off value 0.7. That is because the detection area obtained from this cut-off value differed to a certain extent from that under the other two sets, which led to different results in the calculation of population protection, and hence in site selection.

By applying the model to the case of Toufen Industrial Zone, shows that when only EOS, DA, or PP was considered, the resulting network might be minimally affected by outside sources, cover maximum detection area, or protect largest population respectively, but it failed to grasp high pollution areas. Thus these objectives should not be considered alone, but rather with DC or DDC together. And more objectives were considered simultaneously, the weight combination and the interrelationship between objectives got more complicated. It became necessary to undergo a proper decision-making analysis to determine the weight of each objective.

As for subsequent studies, the authors are currently taking on the topic of how the distribution of multiple pollutants affect the planning of a monitoring network. The authors will also undergo further analysis of the meteorological data in the hope to use less representative data as basis for assessing a monitoring network to minimize the computing load. The authors also hope to improve the construction of models that can include multiple factors to reduce the complexity of result analysis.

## 五、成果自評

本計畫成果符合原進度規劃。且以五個目標進行工業區空氣品質監測站網優選決策，可以避免單目標優選模式可能導致的偏差結果。所提出的一些目標式可改善站址分佈不均的缺點，而考量工業區外污染源的影響可提高監測站網的代表性，多目標結果分析可令決策者更了解不同目標間的折衷關係，相信能協助決策者提昇決策品質。

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