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Multicriteria analysis of environmental quality in Taipei: public preferences and improvement strategies

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The public preferences for environmental quality should be a primary consideration of planners and decision-makers in environmental systems planning. In the first stage of multicriteria analysis, a multi-attribute evaluation model for determining public preferences is formulated. The environmental indices are defined for a comparison of environmental quality in different metropolitan districts. The public preferences of the environmental quality in Taipei are obtained using the weighted average rating method. The results indicate air quality and noise pollution as main public concern. In the second stage of multicriteria analysis, strategies are proposed to improve the air quality, and criteria are established. The experts evaluated all alternative strategies according to the criteria. The alternatives are ranked applying the compromise ranking method.

Keywords: environmental quality, public preference, improvement strategies, multicriteria analysis, compromise solution.

Introduction

The concentration of population and industrial development in many urban areas has led to deterioration of the metropolitan environment and increasing public concern about environmental quality. In Taiwan the percent of PSI > 100 (Pollutant Standards Index) was around 67% (percent of days) between 1984 and 1991, indicating poor (bad) air quality. The Taiwan Environmental Protection Administration (EPA) therefore developed managerial policies based on both administrative controls and economic instruments (Chen and Fang, 1998). The Taiwan Air Quality Monitoring Network (TAQMN) was completed in 1996, with 66 air quality monitoring stations, including 50 new locations. To meet the public needs for a better air quality, the EPA has initiated a plan to supplement the current administrative controls. Public concern about environmental quality has forced the development of evaluation models and the implementation of improvement strategies. The percent of PSI > 100 dropped to 6% currently (from 67%).

A number of environmental evaluation models have been previously developed (Teng and Tzeng, 1994; Ribeiro, 1996; Parson, 1997), and they can be distinguished into two types. One includes quantifiable measures with data obtained through monitoring or surveys, and the other is generally based on people's preferences. In the paper by Parson (1997), two conventional assessment methods,

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formal models and expert panels, are considered, noting that 'weaknesses are in how well present models attain their representational goals'. Since in most cases only a few attributes of the environment are quantifiable, collecting data and formulating integrated models are the primary difficulties in applying formal models. As an alternative to formal modeling, judgments can be gathered from people who have knowledge and experience relevant to the particular problem. In the paper by Margai (1995), manmade environmental hazards and their impact on affected communities are considered; questionnaires were administered by mail to assess the residents' awareness and perception, and the results showing high levels of environmental awareness, specifically, air pollution and waste disposal were cited as the most significant problems. In Teng and Tzeng (1994), the multicriteria evaluation of strategies for improving and controlling air quality in the metropolitan area was considered; experts evaluated feasible strategies, and the ELECTRE III model was used to rank alternatives. Subsequently, the multiattribute utility theory was considered as an applicable approach (Tzeng *et al*., 1996).

In this paper we develop a procedure to determine people's response to environmental quality and to find improvement strategies to satisfy the residents. So, instead of a formal model, an assessment method based on responses of residents is applied, with the main goal of meeting public needs. This evaluation approach starts from the viewpoint of residents, and derives evaluation values and subjective estimates of relative importance (weights) of the attributes from questionnaires completed by the residents. In other words, a multi-attribute evaluation model for examining environmental quality is formulated through a questionnaire to estimate environmental quality. These results become the integrated environmental quality indices (Naito, 1986). This public preference, expressing the people's response to the existing problem, was considered before formulating the criteria for evaluating improvement strategies.

A two-stage model for multicriteria analysis of environmental quality is developed in this paper. In the first stage, the environmental quality analysis is based on the estimation by the residents, expressing their views and feelings. Since the responses and estimates by the residents towards the environment vary due to different activity spaces, designing the investigation to cover the investigated area is critical. The results of the first stage analysis are used to establish the environmental evaluation indices for the comparative regional analysis. In the second stage, these evaluation results are used to formulate the criteria and the improvement strategies for environmental quality in Taipei. All alternatives were evaluated by experts, and the ranking of alternatives was performed by a multicriteria decision making method.

The main contribution of this paper is the development of an assessment method applicable to environmental quality analysis, with the main goal of meeting the perceived needs of residents. Based on the public preferences determined, improvement strategies are established and the best compromise measures are determined using a multicriteria decision making method.

Public preference elicitation technique

In establishing the environmental quality indices for metropolitan regions, a goal hierarchy structure of objectives is first established (Table 1), providing

Table 1. The environmental quality goal structure

Goal	Objectives	Attributes
Environmental quality	Physical environment	Air quality Water quality Land quality
	Public environment	Noise Drainage facility Solid waste Land use cross-interference Park, green areas, open space
	Domestic environment	Space of living Ventilation Availability of light Quality of drinking water

the relationships between the main goal and the attributes.

Investigation of the metropolitan environmental quality can be performed by asking residents to evaluate the attributes and to assign relative importance (weights) to the attributes. The evaluation (subjective) values of the environmental attributes in each district could be obtained from the questionnaires submitted by the respondents. The evaluation data (attributes values and weights) are collected by the procedure similar to the Analytical Hierarchy Process (AHP) developed by Saaty (1980). The AHP method, used in this paper, is presented in the Appendix A.

The evaluation model of the metropolitan environmental quality applied in this paper is based on the weighting method. In the paper by Ribeiro (1996) the weighting methods were considered as 'more widely applied to multiple attribute problems', and they are applicable to problems with the attribute values and relative importance (weights) expressed as linguistic values for presenting the public preference. The model is based on the following relations:

$$u_d(a_i) = \sum_{j=1}^{N_d} w_{ijd} r_{ijd} \Big/ \sum_{j=1}^{N_d} w_{ijd};\ i=1,\ldots,n;\ \forall\, d \quad (1)$$

where:

$u_d(a_i)$ represents the average evaluation value of the attribute a_i (criterion) for district d;

w_{ij} is the relative importance of attribute i given by resident j;

r_{ij} is the evaluation value of attribute i given by resident j;

N_d is the total number of residents participating in evaluation process in district d,

n is the number of attributes.

For a multiple district (D) or metropolitan area, the following relation was used:

$$u_D(a_i) = \sum_{d \in D} (P_d/P_D)\, u_d(a_i);\ i=1,\ldots,n \quad (2)$$

where: P_d indicates the population in district d, and P_D is the population in the entire area D.

This method was applied for the individual districts of a metropolitan area in order to examine the space distribution of public preferences of environmental quality.

It is preferable to prepare histograms of the data to check their distribution before proceeding with weighted average rating, since the shape of the distribution is best communicated visually. Measures of a distribution's deviation could be used, such as standard deviation, coefficient of variation, skewness, and kurtosis (see Table 5). Small values of these measures (close to 0) indicate consensus among the evaluators, whereas large negative kurtosis indicates that the evaluators are far from consensus. If the data are not normally distributed, and the measures of spread are not small, the average value is not representative. If the measures of shape are large (negative kurtosis) for the criteria weights, sensitivity analysis covering the range of weights should be performed within multicriteria decision making procedure.

Public preferences for environmental quality in Taipei

Metropolitan Taipei area

Metropolitan Taipei has an area of 2325 km^2 (Taipei city 273 km^2, and outside Taipei city 2052 km^2) and a total population of 5·9 million (Taipei city 2·6 million and outside the city 3·3 million) with population density of 2555 per km^2 in 1996 (Taipei city 9680 and outside Taipei city 1611). Taipei city is the capital of Taiwan and the center of politics, economics, money market and culture. Urbanization has spread rapidly and dramatically to suburban areas with the growth of the economy and standard of living during the past two decades. The governmental policies and infrastructure investment cannot follow this rapid growth and the changes in residential needs (Chen and Fang, 1998). Tremendous increases in motor transportation have caused deterioration of the metropolitan air quality to an almost intolerable extent. This is exacerbated by the fact that Taipei city is located in a basin, so that emissions are not easily diffused to surrounding areas. Urban residents have realized the seriousness of pollution, especially air pollution created by motor vehicles, and they expect an improvement in environmental quality.

Before 1995 there were years with more than 50% of the days with poor air quality, but environmental quality in Taiwan has improved since 1995, with the percent of PSI $>$ 100 dropping to

6%. In spite of this general improvement, the environmental quality in Taipei should be better. Very often air quality is moderate (PSI > 50), the particulate matter (PM10), and to some extent ozone (O_3), contribute to poor air quality. The case study was undertaken (beginning in 1994) to gather data about public preferences and to determine the best compromise measures for environmental quality improvement, to fulfill human requirements.

Investigation design

This investigation of public preferences about environmental quality was designed to obtain information on: (a) the relative importance (weights) of the environmental quality attributes, (b) the evaluation values of the environmental quality attributes from very dissatisfied to very satisfied, and (c) the basic information observed by the interviewees (checking the locality of investigation). The number of samples (areas) was determined according to the population in each homogeneous district group. Each district was divided into several investigation squares using city maps, so that the uniformity of random samples within each district was maintained. Furthermore, random sampling was performed in each of the investigation areas so that the samples were selected with an even spatial distribution. The total number of samples in this investigation was planned to be 2500, and a minimum sample threshold of 30 was set up for each administrative district. A total of 2739 valid samples were retrieved.

The public preferences

The questionnaire was designed with seven possible answers for the environmental attributes, i.e. very dissatisfied, rather dissatisfied, mildly dissatisfied, fair, mildly satisfied, rather satisfied, and very satisfied. These linguistic values are simply transformed into the real numbers using the linear scaling as: 0, 16·7, 33·3, 50·0, 66·7, 83·3, 100, respectively. The evaluation data (attributes values and weights) are collected by the procedure similar to the Analytical Hierarchy Process (AHP) presented in the Appendix A.

Using this environmental quality assessment, integrated evaluation indices were determined by applying equations (1) and (2). The evaluation values are presented in Table 2, but only the data for characteristic districts (those with maximum or/and minimum value). There are 40 districts in the total area. In Table 2, the last three rows contain data for Taipei city, outside Taipei city area, and the metropolitan area.

The results for the districts show that the residents are very dissatisfied with air quality in Panchiao district outside Taipei city (evaluation value of 9·04) and in Lungshan district (20·25) within Taipei city, both of which are old towns with heavy traffic congestion. Air quality is much better evaluated for Wulai (95·60) and Pinglin (93·95) districts outside of Taipei city, both are in the mountain areas. According to EPA data, both Panchiao and Lungshan, very often have moderate are quality (PSI > 50). The EPA considers Wulai and Pinglin as districts with better air quality. This indicates that the response of residents may have a good correlation with measured data,

Table 2. The evaluation values of the attributes for districts

District	Air quality	Pollut. rivers	Hilly slopes	Noise	Drainage facility	Solid waste	Land use	Parks, O.space	Space living	Ventila-tion	Avail. light	Drinking water
Kuting	34·41	35·61	17·50	36·58	58·05	48·11	57·22	51·49	44·54	61·30	59·96	49·48
Shuangyuan	33·71	27·05	95·00	27·94	82·36	46·12	34·73	56·69	51·95	70·47	60·92	71·21
Lungshan	20·25	32·35	90·51	21·35	57·10	37·30	30·70	29·60	56·55	46·10	50·50	53·91
Chenchung	48·30	42·25	93·12	24·22	92·30	37·30	46·65	45·00	43·35	65·29	64·25	82·89
Panchiao	9·04	28·13	94·31	17·01	38·96	38·68	35·82	36·10	72·87	49·94	47·63	53·37
Sanchung	23·96	30·52	25·75	23·71	31·10	32·30	32·00	25·65	45·03	44·83	43·80	37·90
Yingko	39·50	90·52	51·19	39·28	49·95	49·95	47·75	44·45	54·90	52·15	58·75	56·76
Ssnhsia	70·30	55·31	55·78	65·86	62·05	54·35	59·30	79·65	56·55	62·60	56·55	54·35
Tanshui	47·75	12·31	34·00	39·50	44·68	38·12	48·50	33·54	48·67	51·88	48·21	40·88
Taishan	31·25	17·50	30·41	31·16	68·18	37·30	45·55	30·59	60·95	74·70	75·80	19·15
Pinglin	93·95	49·95	94·50	85·70	79·65	87·90	93·95	11·24	52·15	93·40	89·19	64·80
Wulai	95·60	74·70	79·65	82·95	86·25	87·90	85·70	34·00	76·67	89·55	88·45	87·35
Taipei city	37·82	38·70	49·67	37·05	59·79	47·63	51·74	46·87	54·40	60·07	57·31	55·48
Out. Taipei c.	29·87	33·98	57·99	31·94	50·89	41·62	46·35	36·99	57·34	58·21	54·84	47·20
Metropolitan	33·68	36·24	54·00	34·39	55·15	45·00	48·94	41·73	55·93	59·10	56·03	51·17

and the public preferences could be a base for environmental quality analysis.

The ranking based on minimization of average evaluation values of the attributes for metropolitan area is as follows: air quality (33·68), noise (34·39), pollution of rivers and streams (36·24), parks, green area and open space (41·73), solid waste (45·00), land use cross-interference (conflicts) (48·94), the quality of drinking water (51·17), conservation of hilly slopes (54·00), drainage facility (55·15), space of living (55·93), availability of light (56·03), and ventilation (59·10). This does not mean that the residents are not interested other qualities of their living space, but they do consider air quality as the most serious problem. The results indicate that Taipei city, with a total environmental quality value of 46·98, is slightly better than the suburban area outside Taipei city, with total environmental quality value of 41·81.

The ranking list based on maximization of the average normalized weights (relative importance) of attributes is as follows: air quality (0·132), noise (0·106), pollution of rivers and streams (0·102), solid waste (0·087), quality of drinking water (0·082), conservation of hilly slopes (0·077), space of living (0·077), parks, green areas and open space (0·073), ventilation (0·073), availability of light (0·070), drainage facility (0·062), land use conflicts (0·060). These weights also show that air quality problem is very important in Panchiao district (weight 0·231), but not so important in Wulai district (0·062). The people living in mountain areas like Wulai do not perceive an air quality problem, whereas residents living in a downtown area like Panchiao have negative perceptions.

The data in Table 2 are informative, showing the public concern about environmental quality attributes. These results show that air quality and noise pollution are the most troublesome attributes. Both air and noise pollution are caused by the same sources, primarily motor vehicles, factories and construction works. The entire Taipei city and part of the densely-populated districts outside Taipei city (Taipei Hsien) are located in a basin and emission gases are not diffused to the surroundings. Most air pollution is caused by motor vehicles (mobile pollutants), and in some of the suburban districts outside Taipei city the air pollution is additionally caused by the manufacturing plants (immobile pollutants). These results point out what measures could be considered to improve the satisfaction of residents concerning environmental quality.

Multicriteria analysis of improvement strategies

The most severe and unsatisfactory environmental attributes according to the evaluation results by residents are considered as a main goal for improvement strategies. The results of the public preference investigation indicated that air quality and noise are considered to be the most serious and dissatisfactory attributes for the metropolitan Taipei. Based on this conclusion from the first stage, and because the sources of air pollution and noise are mostly the same, only the strategies for improving air quality are investigated in the next stage. The multicriteria analysis of improvement strategies consists of four main steps, described below.

Generating improvement strategies

Generating alternative strategies requires devising different scenarios, based on understanding problems, experience, knowledge and information for improving environmental quality. Then, relevant strategies are defined for achieving the goal of improving the environmental quality. In the Metropolitan Taipei area, air quality improvement is the main goal according to public preference, the result of the analysis in the first stage.

The deterioration of air quality in metropolitan Taipei is caused by different pollutant sources, which can be divided into two categories: mobile pollutant sources, which are emissions from motor vehicles; and immobile pollutant sources, such as factories, construction work, etc. In this investigation, strategies to improve air quality are formulated through discussions by the experts. Two groups of measures to improve air quality were considered.

Measures to control mobile pollutant sources

(1) *Increasing the traffic flow efficiency.* Through strategies of transportation system management, such as improvement of the traffic signal system, and the implementation of one-way lanes; the frequency of vehicle acceleration, deceleration and stops could be decreased, and air pollutants from motor vehicles could be reduced.
(2) *Reducing traffic flow during peak hours.* Through the adjustment of working hours, such

as using flexible working hours, or by reduction of working days per week, the traffic flow during peak hours as well as emitted pollutants could be reduced.

(3) *Controlling the increase of motor vehicles.* Through methods like the increase of license tax and cost of self-owned parking spaces, the number of motor vehicles could be controlled, decreasing motor vehicle emissions.

(4) *Improving and encouraging travel by mass transportation.* By improving the mass transportation system and its service quality, the public would be encouraged use it, and the use of motor vehicles would be reduced.

(5) *Elimination of old vehicles.* Increasing the examination frequency for old vehicles, as well as establishing a unitary insurance system and a fixed-period maintenance, would reduce the air pollution.

(6) *Encouraging the use of low-pollution fuel.* Through the comprehensive provision of unleaded petroleum and the use of liquefied petroleum gas, the level of emitted pollutants could be decreased.

(7) *Installation of pollution control devices.* The utilization of low-pollution engines, requirements for catalytic converters on new vehicles, and promotions to install catalytic converters on vehicles in use, would lead to reducing emissions.

(8) *Intensifying examination of air emission by motor vehicles.* Through the increased efforts of fixed-period and roadside interception examinations of motor vehicles, repair and maintenance of motor vehicles would be improved.

(9) *Establishing rigid pollution emission standards.* Through the enforcement of emission standards, the owners of motor vehicles would improve their vehicle emission, and to reduce the pollution.

Measures to control immobile pollutant sources

(1) *Controlling construction work.* Through penalties and restriction of the pollution caused by civil engineering and roadside works, the air pollution may be controlled.

(2) *Regulating open air burning.* By investigating incidents and applying pollution penalties for open air burning, air pollution would be reduced.

(3) *Rigid regulation standards.* Through the enforcement of emission control standards for immobile pollution sources, the polluters would decrease the pollution.

(4) *Encouraging manufacturers to install anti-pollution equipment.* By implementing policies such as low-interest loans and tax exemptions, manufacturers would be encouraged to install anti-pollution equipment to reduce the emission of pollutants.

(5) *Pollution taxes.* Based on the emission quantity according to a pollution standard, taxes could be levied upon polluters as external costs. This tax revenue could be used to compensate victims and compel polluters (manufacturers) to lower their emission of pollutants.

(6) *Implementing a system of transferable permit of emission.* Through this anti-pollution system, the government decides the quantity of permit emission according to the conceived total emission of pollutants (Chen and Fang, 1998). Under this system, a polluter has to have permits in order to emit a certain amount of pollutants. Such permits are publicly sold so that once the manufacturers producing massive pollution are able to perform more efficient production and cut down the amount of pollutants, they can reduce pollutants to below the permit level and sell these permits to other manufacturers while the total amount of pollutants remains the same.

Establishing criteria

Establishing criteria is performed in two steps: (1) acceptance of the set of criteria and definition of each criterion, and (2) establishing the way of expressing the relative importance of each criterion. In establishing the criteria, there are five principles: (i) completeness, (ii) decomposability, (iii) nonredundancy, (iv) operational feasibility, and (v) minimum size (Keeney and Raiffa, 1976). The decision-maker could assign weight (as relative importance) for each criterion. The decision-makers for this study were environmental protection experts, government authorities, academic research groups and local residents.

Seven criteria ($f_i, i=1, \ldots, 7$) were established by the decision makers, the first three from implementation aspects, and next three from social aspects.

f_1 – Implementation costs The cost of implementation for measures or improvement strategies is likely to be covered by government funds. Higher costs mean that more funding would be required, and it would be more difficult to obtain the necessary money from the government for implementation.

f_2 – Cooperation of government administration This refers to the degree of government administrative cooperation and support for the strategy implementation. Higher evaluation results mean that the government administration would be more cooperative and supportive.

f_3 – Existing legal acts Higher evaluation results indicate that the supplement and amendment of legal acts would not be a problem.

f_4 – Social equity If the implementation of these strategies would satisfy the public needs, then a higher degree of social equity would be achieved, and the evaluation values are higher.

f_5 – Acceptance by non-polluters The evaluation value should be high if there is a perception that the non-polluters (the general public and non-motor vehicle users) will accept the strategy after its implementation.

f_6 – Acceptance by polluters The evaluation value should be high if there is a perception that the polluters (polluting manufacturers or users of motor vehicles) will accept the strategy after its implementation.

f_7 – Amelioration of air quality The evaluation value should be high if there is a perception that the air quality will substantially improved after implementation of the strategy.

Evaluating the improvement strategies

The final step in evaluation is the generation of a performance matrix. Since quantified information for the improvement strategies is difficult to obtain, the expert evaluation approach was used. Experts may judge the effects of each measure of improvement strategy. In this study linguistic values were used to design the evaluation questionnaire.

The group decision-making approach was employed to evaluate the improvement strategies of air quality. The expert group for decision-making consisted of nine primary members invited from related environmental academic institutes, government authorities, and assemblies of elected representatives. Six additional experts from academic institutes of transportation were asked to joint this group because mobile pollution sources involve transportation and motor vehicles. For the immobile pollution sources, the nine evaluators in the first group evaluated the air quality improvement strategies. All measures to control pollutant sources were evaluated according to established criteria for improving air quality. The linguistic values: very very high, very high, high, median, low, very low, and very very low, were transformed by scaling into the numbers: 100, 83·3, 66·7, 50·0, 33·3, 16·7, 0, respectively.

The evaluation results were obtained as the performance matrix (measures versus criteria); in this case there are two matrices, one for mobile polluters and one for immobile polluters. The data obtained are presented in Tables 3 and 4. The first criterion function (f_1) has to be minimized, and all others have to be maximized. The results obtained by the Factor Analysis show that there is no dependency between the criterion functions ($f_i, i=1, \ldots, 7$).

Within the weight assessment procedure, fifteen experts gave values to the weights. The values given were analyzed in order to test the representativeness of the mean values. The data in Table 5 show that the distribution of weights is right (positive) skewed, with the weight values stretch toward larger values. For instance, for the weight w_5 there is one value of 0·577, but the kurtosis indicates the distribution similar to normal. For the weight w_7, the negative kurtosis shows that there is no consensus among the evaluators; the values of w_7 are more evenly distributed (platykurtic shape). The measures of shape and spread are not small, although the weight stability intervals show that sensitivity analysis covering the range of weights is not necessary (see Table 8).

Multicriteria ranking and compromise solution

Among the numerous approaches available for conflict management, the most prevalent include multicriteria decision making (MCDM). Practical problems are often characterized by several non-commensurable and competing (conflicting) criteria, with no solution satisfying all criteria simultaneously. Applying MCDM, the compromise solution for problem with conflicting criteria can be determined, which can help decision makers to reach a final decision.

The compromise ranking method (named VIKOR) is introduced as one applicable technique to implement within MCDM, and it is presented in

Table 3. The values of criterion functions (for mobile polluters)

Alternatives	Criterion functions						
	f_1	f_2	f_3	f_4	f_5	f_6	f_7
1 Increasing traffic flow efficiency	49·37	45·19	46·91	55·42	63·87	65·71	52·15
2 Reducing traffic during peak hours	59·67	40·07	41·58	54·93	63·41	46·60	58·15
3 Controlling growth of m. vehicles	56·27	40·66	45·96	38·23	70·49	32·45	69·98
4 Mass transportation	59·48	52·60	45·03	63·45	67·55	50·59	70·05
5 Elimination of old vehicles	47·62	48·36	58·28	50·84	64·13	40·35	60·23
6 Use of low-pollution fuel	39·46	40·86	48·44	56·00	70·67	65·32	75·12
7 Installation of poll. control devices	54·00	55·49	61·00	59·37	78·05	40·15	71·83
8 Intensifying exam. of air emission	55·44	51·35	48·39	57·42	73·18	44·71	49·63
9 Establishing rigid standards	36·42	52·58	58·85	67·43	79·28	36·49	65·24

Table 4. The values of criterion functions (for immobile polluters)

Alternatives	Criterion functions						
	f_1	f_2	f_3	f_4	f_5	f_6	f_7
1 Controlling construction work	48·02	48·18	52·09	72·38	80·76	33·20	58·99
2 Regulating open air burning	42·57	37·50	48·82	64·17	80·76	30·20	47·56
3 Rigid regulation standards	31·70	49·89	62·51	69·93	74·84	24·91	68·11
4 Install anti-pollution equipment	53·55	42·06	52·32	47·49	66·24	42·08	70·11
5 Pollution taxes	29·87	51·16	48·69	58·97	80·08	21·41	60·23
6 Transferable permit of emission	33·10	44·36	59·30	59·51	78·33	44·58	63·79

Table 5. The values of criteria weights

	Weights						
	w_1	w_2	w_3	w_4	w_5	w_6	w_7
Mean	0·070	0·164	0·157	0·118	0·108	0·062	0·320
Median	0·069	0·077	0·134	0·107	0·046	0·035	0·297
Coefficient of Variation	0·824	1·019	0·761	0·721	1·275	1·083	0·623
Skewness	1·371	1·059	0·995	1·323	2·545	1·789	0·597
Kurtosis	1·812	−0·181	−0·234	1·036	6·038	2·021	−1·004

the Appendix B. Compromise ranking is performed by comparing the measure of closeness to the ideal alternative (Duckstein and Opricovic, 1980). This method was applied with data (average evaluation values and weights) given by the expert group. The obtained ranking lists are presented in Table 6, for mobile polluters, and in Table 7 for immobile pollutes. There are two compromise solutions for immobile polluters obtained by VIKOR, because the top two are 'close'.

In addition, the ranking results are obtained by applying another method, the Technique for Order Preference by Similarity to Ideal Solution (known as TOPSIS), which is also a modification of compromise programming (similar to VIKOR). This method was developed based on the concept that, using Euclidean distance, the chosen alternative should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution, and on the entropy method to modify weights (Hwang and Yoon, 1981). The ranking results (by TOPSIS) are presented in Table 6 and in Table 7. The results obtained using the two methods (VIKOR and TOPSIS) suggest that the differences are due to different weights (TOPSIS uses modified weights). With the same weights the results of the two methods are almost the same.

The VIKOR algorithm determines the weight stability intervals (Opricovic, 1994) for the obtained compromise solution with the 'input' weights, given by the experts. The values of weight range (given $w_{\min}$, $w_{\max}$) and stability interval (w_L^m, w_R^m, for mobile polluters; and w_L^{im}, w_R^{im}, for immobile polluters) presented in Table 8 show the preference stability of obtained compromise solutions, with a few exceptions, such as $w_{R,1}^m$, $w_{R,5}^{im}$, $w_{R,6}^{im}$, $w_{L,7}^m$.

As a compromise solution, the following measure could be proposed for implementation: mobile polluters should promote and implement the utilization of low-pollution engines and

Table 6. Ranking list of measures to control mobile polluters

Ranking by VIKOR			Ranking by TOPSIS	
Rank	Index Q	Measure	Rank	Index
1.	0·0	Installation of pollution control devices	3	0·614
2.	0·168	Establishing rigid pollution emission standards	4	0·542
3.	0·333	Mass transportation	2	0·628
4.	0·345	Use of low-pollution fuel	1	0·777
5.	0·537	Elimination of ruined vehicles	7	0·415
6.	0·569	Controlling the growth of motor vehicles	6	0·433
7.	0·802	Reducing traffic flow during peak hours	8	0·357
8.	0·864	Increasing the traffic flow efficiency	5	0·466
9.	0·874	Intensifying examination of air emission	9	0·293

Table 7. Ranking list of measures to control immobile polluters

Ranking by VIKOR			Ranking by TOPSIS	
Rank	Index Q	Measure	Rank	Index
1.	0·0	Rigid regulation standards	2	0·549
2.	0·186	Transferable permit of emission	1	0·810
3.	0·397	Controlling construction work	5	0·413
4.	0·422	Pollution taxes	4	0·464
5.	0·432	To install anti-pollution equipment	3	0·511
6.	1·000	Punishing open air burning	6	0·307

Table 8. Weight range and stability interval

i	w_L^{im}	w_L^m	$w_{\min}$	w_i	$w_{\max}$	w_R^m	w_R^{im}
1	0·0	0·0	0·008	0·070	0·236	0·143	0·749
2	0·0	0·0	0·006	0·164	0·554	1·0	0·736
3	0·0	0·0	0·037	0·157	0·430	1·0	1·0
4	0·0	0·0	0·022	0·118	0·336	0·312	0·699
5	0·0	0·0	0·011	0·108	0·577	0·580	0·263
6	0·0	0·0	0·012	0·062	0·249	0·196	0·130
7	0·0	0·152	0·096	0·320	0·685	0·685	0·808

the installation of catalytic converters, whereas immobile polluters should establish rigid emission standards and implement a system of transferable emission permits. However, all of the top four measures in the ranking lists for mobile polluters may be considered for implementation.

Conclusions

A two-stage model for multicriteria analysis of environmental quality in the metropolitan area is developed. In the first stage, the environmental quality analysis is based on the estimation by the residents, expressing their views. In the second stage, the evaluation results are used to formulate the criteria and the improvement strategies of the environmental quality. The experts evaluated the alternative strategies, and then the ranking of alternatives was performed by two multicriteria decision making methods.

Environmental evaluation indices are a subjective manner, reflecting the actual responses and preferences of residents towards environmental quality. Their expressed preferences have to be considered by planners and decision-makers during policy formulation. Public preferences obtained in the first stage of the presented methodology indicate that air quality is the most urgent matter to deal with in order to improve environmental quality in Taipei. The results of the second stage provide a compromise improvement measure which should be implemented in order to improve the air quality. This assessment method is based on data-gathering and on evaluation of alternatives by experts, without using a mathematical model of environmental management, and this approach could be considered as a contribution of this paper.

The results of multicriteria analysis indicate *what* to do first in order to improve environmental quality. To answer the questions *where* and *when* to implement the improvement strategies over metropolitan districts, the research should continued by solving the allocation and scheduling problem under budgetary constraints. The combination of policy measures could be analyzed as a portfolio synergy case.

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Appendix A

The analytical hierarchy process – AHP

The Analytical Hierarchy Process (AHP) is a systematic procedure for representing the elements of a problem, hierarchically. The AHP method was developed by Saaty in 1971 (Saaty, 1980; Saaty and Vargas, 1982). The procedures, used in this paper, may be summarized as follows:

(1) Structuring the hierarchy, for evaluation

The AHP method is used to make the decomposition (or structuring) of the problem as a hierarchy. In general, the AHP method divides the problem into three levels: (a) the goal for resolving problem; (b) the objectives for achieving the goal; (c) the evaluation criteria for each objective. An example of hierarchy is presented in Table 1.

(2) Constructing the pairwise comparison matrix

After structuring a hierarchy, the pairwise comparison matrix for each level is constructed. During the pairwise comparison the nominal scale is used for evaluation.

The scale of relative importance is presented in Table A.1. In the evaluation process (by experts), the AHP questionnaire sheet for environmental quality is used. The sheet for the objective level, as an example, is presented in Table A.2, and it could be used in comparing objectives, one on the left with one on the right side. In Table 1 there are three objectives.

(3) Calculating the weights and testing the consistency for each level

For each pairwise comparison matrix ($\boldsymbol{A}$), using the theory of eigenvector, i.e. ($\boldsymbol{A}$-$\lambda_{\max}$ I) $\boldsymbol{w} = \boldsymbol{0}$, to calculate the eigenvalue ($\lambda_{\max}$) and the eigenvector $\boldsymbol{w} = (w_1, w_2, \ldots, w_n)$, weights can be estimated. The consistency of the comparison matrix was tested and the opinions of the regional decision-maker group were integrated. In the consistency test, consistency index (C.I.) could be utilized to determine the degree of consistency, generally speaking, when C.I. $< 0{\cdot}1$ it is considered to be acceptable.

Table A.1. Scale of relative importance

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Intermediate between equal and weak	
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
4	Intermediate between weak and strong	
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
6	Intermediate between strong and demonstrated	
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
8	Intermediate between demonstrated and absolute	
9	Absolute or extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above non-zero numbers	If activity *i* has one of the of above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	Reasonable assumption

Table A.2. AHP questionnaire sheet for environmental quality

	Importance																	
Physical Environment	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Public Environment
Physical Environment	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Domestic Environment
Public Environment	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Domestic Environment

Marking in questionnaire (Table A.2), for example, 5:1 means that physical environment is of strong importance over public environment.

Appendix B

The VIKOR method

The compromise ranking method (named VIKOR) has been introduced as one applicable technique to implement within MCDM (Opricovic, 1998). Assuming that each alternative is evaluated according to each criterion function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative. The multicriteria merit for compromise ranking is developed from the *Lp-metric* used in compromise programming method (Yu, 1973; Zeleny, 1982). The various alternatives are denoted as $a_1, a_2, \ldots, a_J$. For an alternative a_j the merit of i-th aspect is denoted by f_{ij}, i.e. f_{ij} is the value of i-th criterion function for the alternative a_j; n is the number of criteria.

Figure B.1 illustrates ideal $F^* = (f_1^*, f_2^*)$ and compromise solution $F^c = (f_1^c, f_2^c)$ within bicriteria problem; a compromise as an agreement established by mutual concessions is illustrated by $f_1^c \leq f_1^*$ and $f_2^c \leq f_2^*$.

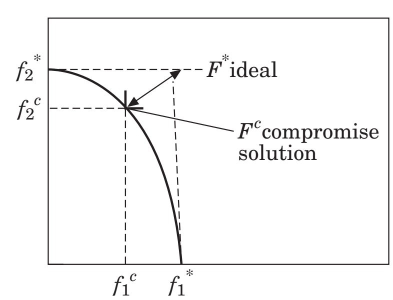

Figure B.1. Illustrating compromise.

Compromise programming method introduced L_p-*metric* as an aggregated function. The development of VIKOR method started with the following form of L_p-*metric*

$$L_{p,j}=\left\{\sum_{i=1}^{n}[w_i(f_i^*-f_{ij})/(f_i^*-f_i^-)]^p\right\}^{1/p},$$
$$1\le p\le\infty;\ j=1,2,\ldots,J$$

Within VIKOR method $L_{1,j}$ (as S_j) and $L_{\infty,j}$ (as R_j) are used in formulating ranking merit ('boundary solutions'). The solution obtained by $\min_j S_j$ is with a maximum 'group utility' ('majority' rule), and the solution obtained by $\min_j R_j$ is with a minimum individual regret of the 'opponent'.

Weighting coefficients (weights w_i) are introduced to express the relative importance of the criteria. The weights have no clear economic meaning, but the use of weights gives the opportunity for modeling the real decision making.

The compromise ranking algorithm VIKOR has the following steps:

(a) Determination of the best f_i^* and the worst f_i^- values of all criterion functions, $i=1,2,\ldots,n$.

If the i-th function represents a benefit than:

$$f_i^*=\max_j f_{ij},\quad f_i^-=\min_j f_{ij}$$

(b) Compute the values S_j and $R_j, j=1,2,\ldots,J$, by the relations

$$S_j=\sum_{i=1}^{n}w_i(f_i^*-f_{ij})/(f_i^*-f_i^-)$$
$$R_j=\max_i[w_i(f_i^*-f_{ij})/(f_i^*-f_i^-)]$$

where w_i are the weights of criteria.

(c) Compute the values $Q_j, j=1,2,\ldots,J$, by the relation

$$Q_j=v(S_j-S^*)/(S^- -S^*)+(1-v)(R_j-R^*)/(R^- -R^*)$$

where:

$$S^*=\min_j S_j,\quad S^-=\max_j S_j,$$
$$R^*=\min_j R_j,\quad R^-=\max_j R_j$$

v is introduced as weight of the strategy of 'the majority of criteria' (or 'the maximum group utility'), usually $v=0{\cdot}5$.

(d) Rank the alternatives, sorting by the values S, R and Q. The results are three ranking lists.

(e) Propose as a compromise solution the alternative (a′) which is the best ranked by the measure Q if the following two conditions are satisfied:

C1. 'Acceptable Advantage':

$$Q(a'')-Q(a')\ge DQ$$

where: a'' is the alternative with second position in the ranking list by Q; $DQ=1/(\mathrm{J}-1)$; J is the number of alternatives. ($DQ=0{\cdot}25$ if $\mathrm{J}\le 4$).

C2. 'Acceptable Stability in decision making':

The alternative a′ also has to be the best ranked by S or by R, or by both, as well. This compromise solution is stable within a decision making process, which could be: 'voting by majority rule' (when $v>0{\cdot}5$ is needed), or 'by consensus' $v\approx 0{\cdot}5$, or 'with veto' ($v<0{\cdot}5$). Here, v is the weight of decision making strategy 'the majority of criteria' (or 'the maximum group utility').

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

> Alternatives a′ and a'' if only the conditions C2 is not satisfied, or
> Alternatives a′, a'',..., $\mathrm{a}^{(\mathrm{k})}$ if the conditions C1 is not satisfied; $\mathrm{a}^{(\mathrm{k})}$ is determined by the relation $Q(\mathrm{a}^{(\mathrm{k})})-Q(\mathrm{a}')\approx DQ$ (the positions of these alternatives are 'in closeness').

The best alternative, ranking by Q, is one with the minimum value of Q.

The main ranking result is the compromise ranking list of alternatives, and the compromise solution with the 'advantage rates'.

Ranking by this algorithm may be performed with different values of criteria weights w_i, analyzing the impact of criteria weights on proposed compromise solution. The VIKOR algorithm determines the weight stability intervals, for the obtained compromise solution with the 'input' weights, indicating the preference stability of obtained compromise solution. This is a helpful tool in multicriteria decision making, particularly in the situation when the decision maker is not able to express preference at the beginning of system design. The compromise solution could be accepted by the decision makers because it provides a maximum 'group utility' of the 'majority' (with measure S, representing 'concordance'), and a minimum of individual regret of the 'opponents' (with measure R, representing 'discordance').