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Multicriteria Evaluation for Strategies of Improving and Controlling Air Quality in the Super City: a Case Study of Taipei City

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The deterioration of air quality in big cities is closely related to transportation. Thus, the application of transportation means to improving and controlling the air quality of metropolitan areas is a correct and functioning method. Among several feasible improvement policies, transportation system management (TSM) is a kind of low-cost method which can be expected to show effects in a short-term period. It would necessitate a great deal of manpower, effort and time if each one of these methods were to be measured precisely and objectively. As a result, the utilization of an expert evaluation model to extract professional knowledge from various fields so as to locate views of consensus would result in a successful decision-making method under circumstances where information is incomplete.

This paper puts forward three phases of a multicriteria evaluation model which will, at the onset, perform consensus elimination under key criteria so as to find out non-dominated strategies; next, every expert uses the ELECTRE III model to rank non-dominated strategies under multiple criteria; the consensus ranking method proposed by Cook and Seiford (1978) is then employed for uncovering the ranking of minimal recognition differences from all experts. This paper takes Taipei city as an illustration to elaborate the intended method.

Keywords: TSM strategies, air quality, MCDM, ELECTRE III, consensus.

1. Introduction

The deterioration of air quality in a large city or metropolitan area is strongly linked to transportation. Transportation-related air pollutants are mainly generated from the emissions of various motor vehicles, which include carbon monodioxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x). In the latter period of 1970, 93 metropolitan

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areas in America were listed with records of CO concentration higher than CO air-quality standards, while the nitrogen dioxide (NO_2) concentration in six metropolitan areas were found to be higher than NO_2 air-quality standards (Horowitz, 1982). In the middle of 1970, air pollutants in most American cities contained 90–100% of CO, 40–90% of HC and 30–80% of NO_x, all of which were largely brought about by moving vehicles (Horowitz, 1982). With Taipei as an example, approximately 99·5% of CO, 91% of HC and 94% of NO_x generated in 1987 were produced by moving vehicles (Tzeng and Teng, 1989).

To improve or control the air quality of metropolitan areas, efforts have to be devoted to vehicle-related items such as improving vehicle production techniques, enactment of environmental protection and the strategic implementation of transportation system management (TSM). Upgrading the vehicle production technique is an enduring amelioration policy which requires massive research and development, the effects of which cannot be relied on for improving air pollution in metropolitan areas in the short term. As for the enactment of environmental protection, its main purpose is to enforce sterner emission standards for newly-sold vehicles so as to reduce vehicle emissions of CO, HC and NO_x. Thus, the average CO emission per vehicle travelled decreased by 20% between 1970–1977, average HC emission per vehicle decreased by 30% and average NO_x emission per vehicle decreased by 10% after stricter vehicle emission standards were employed in America beginning in 1963 (U.S. EPA, 1978). The Republic of China on Taiwan stipulated a vehicle emission standard in 1978, and expected to achieve the 1983 year standard of America in 1980. Though lifting emission standards can apply to newly-sold vehicles, the maintenance of vehicles in use, acceleration and deceleration of vehicles in motion, and ageing and deterioration of vehicles cannot be placed in the constraint. Thus, if the number of vehicles is rising swiftly, the desirable objective of high emission standards will have to be achieved over a longer period of time. For the implementation of the TSM strategy, management techniques are primarily utilized to improve the existing transportation system for optimal efficiency so as to reduce vehicle emission in metropolitan areas and control and improve air quality. According to the research produced in 1980 by the Department of Transportation of America, traffic signalization and any other amelioration policy can reduce CO emission by 33·87% annually, HC emission by 37·83% and NO_x emission by 33·33% (Stevens, 1987), which indicates the tremendous results achieved.

Deterioration of air caused by transportation problems should be dealt with by transportation measures, as they are clear and effective methods. Because TSM is a short-term amelioration policy for urban transportation, hardly any past records of implementation can be referred to; thus, the selection of suitable TSM strategies and its implementation are major issues when transportation techniques are employed to improve the air quality of metropolitan areas. In most of the situations, most had applied benefit–cost analysis (BCA) (Batchelder *et al.*, 1983; Reinke and Curry, 1983; Polus and Tomecki, 1985), cost-effectiveness analysis (CEA) (Batchelder *et al.*, 1983; Reinke and Curry, 1983; Polus and Tomecki, 1985) and scoring methods (Odum *et al.*, 1976). Among these evaluation methods, BCA and CEA necessitate objective and quantified cost data which can exhaust awesome amounts of manpower and resources, and evaluation can be very tough when various TSM strategies are available. The scoring method cannot be relied upon for detailed analysis because it is too subjective and over-simplified.

Because the theory and analysis technique of multiple criteria decision making (MCDM) become nature, it has been widely applied to each and every field (Keeney and

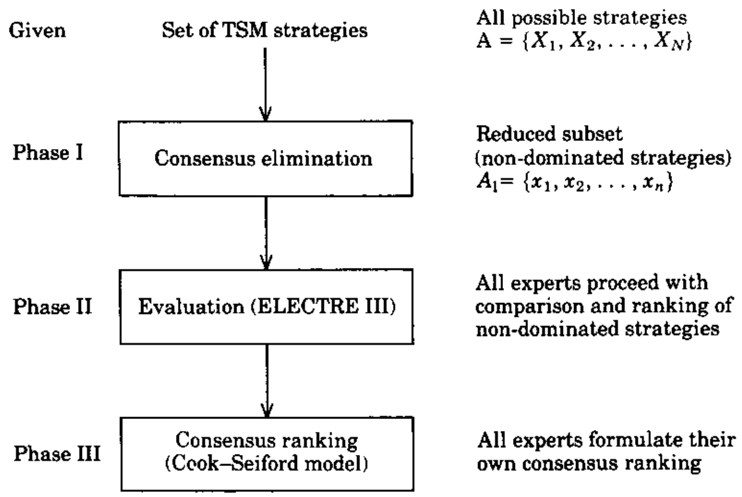

Figure 1. Consensus evaluation framework

Raiffa, 1976). In terms of TSM strategy evaluation, the goal achievement method has been largely used for research, see Larwin and Stuart (1976), Reinke and Curry (1983), Polus and Tomecki (1985) and Won (1990). Other methods are the additive utility function (Lima, 1980), the combinatorial evaluation method of PATTERN and ELECTRE II (Tzeng and Shiau, 1987), concordance analysis (Won, 1990) and compromise solution (Won, 1990).

When various TSM strategies are viewed for possibilities for improving air quality in metropolitan areas, experts of related fields are relied on for their professional qualifications to judge and find some strategies and have them executed. For past MCDM methods utilized on TSM strategy evaluation, consideration of expert consensus was never observed. This paper puts forward the evaluation model in consideration of expert consensus and takes Taipei city as an example for its case study.

2. Framework for consensus evaluation

The purpose of employing R number of experts from related fields to proceed with TSM strategy evaluation is to be assisted by them professionally and experientially so as to find out a strategy of consensus from N feasible TSM strategy sets $A = \{X_1, X_2 \ldots, X_N\}$ (usually the number of N is large). The consensus evaluation model put forward by this paper contains three specific phases, including consensus elimination, evaluation of non-dominated strategies and consensus ranking of non-dominated strategies (as shown in Figure 1).

2.1. PHASE I: CONSENSUS ELIMINATION

The key criterion to view whether a TSM strategy can be executed is its feasibility. According to this criterion, R number of experts can compare two feasible TSM strategies dealing with environmental and traffic situations of metropolitan areas. Afterwards, a TSM strategy of consensus from most of the experts can be concluded integrating compared results of R number of experts. Detailed evaluation will be followed subsequently.

2.2. PHASE II: EVALUATION

According to various n non-dominated strategies derived from elimination, R number of experts will utilize the ELECTRE III model, respectively, to evaluate under m criteria, and, finally, the ranking of n non-dominated TSM strategies can be obtained from R number of experts.

2.3. PHASE III: CONSENSUS RANKING

R number of experts share different modes of opinions in terms of n non-dominated strategies, and that results in alternate ranking. This paper has applied the consensus ranking method presented by Cook and Seiford (1987) in order to find out TSM strategies with a minimal consensus gap from R number of experts. In the following three sections, elaborations are made on consensus elimination, the ELECTRE III model and the consensus ranking method.

3. Consensus elimination

When many TSM strategies (this indicates N is great) for improving air quality of a metropolitan area are open, great amounts of time will be wasted if R number of experts move directly into evaluation with the ELECTRE III model. It is worth considering whether these experts are willing to spend such great amounts of time on evaluation. In most of the cases, elimination can be done first to downgrade the level of evaluation complexity among MCDM evaluation methods. As a result, projects or strategies numbered better or non-dominated can be located (Mahamassani and Krzysztofowice, 1983; Wohl and Hendrickson, 1984; Ebrahim and Cox, 1986; Anandalingam and Olsson, 1989). The applicability of past proposed elimination methods was mostly confined to issues of a single decision maker. Thus, the issue of group decision making remains a challenge. This section will put forward a plain and easy-working consensus elimination method with the participation of several decision makers.

Under the key criterion of implementation feasibility, R number of experts will proceed to pairwise comparison of N strategies from N feasible TSM strategies so as to decide the level of implementation feasibility among two strategies. The objective of pairwise comparison is to minimize the margin of judgment as well as to evaluate more smoothly. Take $d_{jj'}^h$ for instance, it denotes the judgment value of h ($h=1,2,\ldots, R$) experts towards X_j and $X_{j'}$ strategies ($j,j'=1,2,\ldots, N$) under the criterion of implementation feasibility; should X_j strategy be more likely to be executed than $X_{j'}$ strategy or both enjoy tantamount implementation feasibility, then:

$$d_{jj'}^h = \begin{cases} 1, & \text{if } X_j \geqslant X_{j'} \\ 0, & \text{otherwise} \end{cases}. \tag{1}$$

If $X_j \geqslant X_{j'}$ it indicates that the implementation feasibility of X_j strategy is higher than or tantamount to that of $X_{j'}$ strategy.

R number of binary judgment matrix D^h can be obtained from the judgment results of R number of experts, that is:

$$D^h = \{d_{jj'}^h \mid X_j, X_{j'} \in \geqslant A\}, \quad \text{for any } h \tag{2}$$

comprehensive judgment matrix D can be obtained after integrating judgment results of R number of experts, which is as follows:

$$D=\{d^T_{jj'} \quad | d^T_{jj'}=\sum_{h=1}^{R} d^h_{jj'} \quad |X_j, X_{j'} \quad \in A\}. \tag{3}$$

Since experts of diverse fields share different kinds of opinions, how can the advantages and disadvantages of implementation feasibility of the two TSM strategies be decided? This paper has selected the majority rule to determine judgment of consensus from most of the experts, that is:

$$e_{jj'}= \begin{cases} 1, \text{ if } d^T_{jj'} \quad \geqslant M \\ 0, \quad \text{otherwise} \end{cases}. \tag{4}$$

In the equation (4), $e_{jj'}$ indicates the judgment result of consensus of most experts, the value of M can be concurrently discussed and decided by R number of experts who will be applying either the majority rule (over half) or two-thirds rule upon the level of consensus desirable to be achieved. In terms of the majority rule, then:

$$M= \begin{cases} (R/2)+1, & R \text{ is even} \\ [(R-1)/2]+1, & R \text{ is odd} \end{cases}. \tag{5}$$

Judgment matrix E of consensus can be derived at last from R number of experts after elimination by majority rule, which is as follows:

$$E=\{e_{jj'}\}, X_j, X_{j'} \in A. \tag{6}$$

The sum of row of matrix E is α_j ($j=1,2,...,N$), which indicates the level of superiority of TSM strategy X_j to other TSM strategies under the criterion of implementation feasibility.

As compared to other TSM strategies, it says that there is a higher feasibility of implementation as α_j becomes greater; how great the value of α_j has to be before TSM strategy can be considered as non-dominated strategies. This will be decided by R number of experts. For instance, let α_j be greater than $N/2$, then:

$$X_j \in A_1 \quad \text{if } \alpha_j > N/2. \tag{7}$$

Upon this equation, n number of non-dominated TSM strategies $A_1=\{x_k\}(k=1,2,...,n)$ can be obtained.

4. Detailed evaluation of non-dominated strategies

R number of experts will proceed with a thorough evaluation, once n non-dominated strategies have been eliminated from consensus. During this phase, R experts may also evaluate m criteria so as to find out the priority of n non-dominated strategies. Among MCDM discrete evaluation models, the notion of fuzziness is introduced in the ELECTRE III model so as to take note of uncertainty, while pairwise comparison will be utilized so that the decision makers can move to an easier comparison between the advantages and disadvantages. Furthermore, because the relation of disadvantage and advantage doesn't need to satisfy the transitivity supposition, its preference relation can match more realistic issues. The ELECTRE III model, meanwhile, is also applicable to unquantifiable issues (Roy *et al.*, 1986).

This paper intends to make use of a qualitative scale of 1–10 for indication, and then every expert will head onto their professional judgment as TSM strategy evaluation can barely be quantified objectively under the impact values of various criteria. In terms of weights under m criteria, R experts can have located them, respectively, according to the eigenvalue method developed by Saaty (1977). For every expert, the judgment results of impact value of every strategy according to criterion weight and criterion can be evaluated using the ELECTRE III model.

The evaluation procedures of the ELECTRE III model encompass the establishment of threshold function, disclosure of concord index and discord index, confirmation of credibility degree, and the ranking of strategies, which are further elaborated below.

4.1. THE ESTABLISHMENT OF THRESHOLD FUNCTION

$q(g)$ and $p(g)$ represent separately indifference threshold and preference threshold, if $g(a) \geqslant g(b)$ such that:

$$\text{(a) } g(a) \geqslant g(b) \leftrightarrow {}_aP_b \tag{8}$$

$$\text{(b) } g(b) + q(g(b) < g(a) \leqslant g(b) + p(g(b)) \leftrightarrow {}_aQ_b \tag{9}$$

$$\text{(c) } g(b) \leqslant g(a) \leqslant g(b) + q(g(b)) \leftrightarrow {}_aI_b, \tag{10}$$

where P is strong preference; Q is weak preference; I is indifferent; $g(a)$ is the evaluation value of strategy a.

To avoid any inconsistency, the establishment of a threshold function has to satisfy the subsequent constraint equations:

$$\text{(a) } g(a) > g(b) \rightarrow g(a) + q(g(a)) \geqslant g(b) + q(g(b))$$
$$g(a) + p(g(a)) \geqslant g(b) + p(g(b)). \tag{11}$$

(b) For the all criteria of $p(g) > q(g)$, then g is pseudo criteria.

4.2. CONCORD INDEX AND DISCORD INDEX

Concord index $c(a,b)$ is the minimal level of satisfaction of an expert for selecting strategy a and not strategy b, its calculation equation is as follows:

$$c(a,b) = \sum_{j \in J} p_j \, \delta_j(a,b), \tag{12}$$

where p_j is the weight of criterion j and $\delta_j(a,b)$, is the marginal credibility degree of strategy a and strategy b under criterion j, and their calculation equation is as follows:

$$\delta_j(a,b) = 0 \quad \text{if } g_j(b) - g_j(a) \geqslant p_j(g_j(a)) \tag{13}$$

$$\delta_j(a,b) = 1 \quad \text{if } g_j(b) - g_j(a) \leqslant q_j(g_j(a)) \tag{14}$$

$$\delta_j(a,b) = (p - (g_j(b) - g_j(a)))/(p - q) \quad \text{if } q \leqslant g_j(b) - g_j(a) \leqslant p. \tag{15}$$

Discord index $d(a,b)$ is the greatest level of dissatisfaction of an expert for selecting strategy a and not strategy b, its calculation equation is as follows:

$$d_j(a,b) = 0 \quad \text{if } g_j(b) - g_j(a) \leqslant p_j(g_j(a)) \tag{16}$$

$$d_j(a,b) = 1 \quad \text{if } g_j(b) - g_j(a) \geqslant v_j(g_j(a)) \tag{17}$$

$$d_j(a,b) = ((g_j(b) - g_j(a)) - p)/(v - p) \quad \text{if } p \leqslant g_j(b) - g_j(a) \leqslant v, \tag{18}$$

where p is the preference threshold value, q is the indifference threshold value and v is the veto threshold value.

4.3. CREDIBILITY DEGREE ($S(a,b)$)

$$S(a,b) = c(a,b) \quad \text{if } d_j(a,b) > c(a,b) \quad \forall j \in J \tag{19}$$

$$S(a,b) = c(a,b) \times \prod_{j \in J} (1 - d_j(a,b))/(1 - c(a,b)) \tag{20}$$

$$J^* = \{j \in J \mid d_j(a,b) > c(a,b)\}. \tag{21}$$

Credibility degree helps reflect the trend of plus and minus of two strategies. Roy suggested that the decision maker or expert should set up a discrimination function ($S(\lambda)$) as a basis for discerning ups and downs.

4.4. RANKING METHOD OF STRATEGY

With a reliable calculation result of credibility, the advantage and disadvantage order of TSM strategies can find ranking on it, and its management procedures can be seen in three steps: one goes downward, the second goes upward and the final order.

4.4.1. *The downward method*

(i) First, $A^{(k)}$ denotes the set of all non-dominated strategies, $S(a,b)$, credibility matrix and $S(\lambda)$ the discrimination function, $k = 0$, $l = 1$

(ii) Find:

$$\lambda_0 = \max_{(a,b) \in S(a,b)} S(a,b) \tag{22}$$

$$\lambda_1 = \max_{(a,b) < \lambda_0 - S(\lambda)} S(a,b). \tag{23}$$

(iii) Proceed with a pairwise comparison to all strategies:

$$\text{If } S(a,b)>\lambda_1 \text{ and } S(a,b)>S(a,b,)+S(S(a,b)), \tag{24}$$

then a is superior to b.

(iv) $P_b\,(a)$ is the number of strategy a being superior to strategy b ($b \in A^{(k)}$), $f_b\,(a)$ is time the number of strategy a being inferior to strategy b ($b \in A^{(k)}$) and $q_b(a) = P_b(a) - f_b(a)$.

(v) Find max $q_b(a)$, make a strategy set as $U^{(k)}$, if the integer of $U^{(k)}$ strategy is larger than 2, then find λ_{l+1} and return to step (iii) until $\lambda_{l+1}=0$, then go to step (vi), otherwise go to step (vi)

(vi) The ranking of present $U^{(k)}$ set is $V_1(x)=k+1$.

(vii) $A^{(k+1)}=A^{(k)}-U^{(k)}$, if $A^{(k+1)}=0$ then stop; if $k=k+1$ return to step (ii).

4.4.2. *The upward method*

The calculation will run the order from the top to bottom, only at step (v) find min$q_b(a)$, and temporary order $a(x)$ can be obtained, then adjust $a(x)$ according to the ensuing equation, which can bring about result $V_2\,(x)$ of upward order:

$$V_2(x)=1+a_{\max}-a(x),\ x \in A_1 \tag{25}$$

$$a_{\max}=\max_{x \in A_1} a(x). \tag{26}$$

4.4.3. *Final order* V(x)

Final order can be obtained after downward order and upward order are evened in total, that is:

$$V(x)=(V_1(x)+V_2(x))/2,\ x \in A_1 \tag{27}$$

5. Consensus ranking

R kinds of diverse ranking can be obtained as the n TSM strategies of set A_1 of non-dominated strategies are evaluated by preference judgment and the ELECTRE III model of every expert. The ranking result of every expert is not exactly of complete ordinal ranking, because some strategies can be in tie ranking to each other. Under such circumstances, the consensus ranking method proposed by Cook and Seiford (1978) is suitable for it.

Set the ranking of n non-dominated strategies as $H=(a_1,\ldots,a_g,\ldots,a_n)$, a_g denoting the ranking of the No. g non-dominated strategy, and a tie indicated by an average value. For instance, the ranking of TSM strategies a,b,c,d, $H=(b,a,d,c)=(2,1,4,3)$ indicates that the ranking of a is 2, b ranks 1, c ranks 4, and d ranks 3; if the ranking is $H=(a^c_d b)$, this shows that the ranking of a is 1, c and d are tied so their ranking number can be indicated by $(2+3)/2=2{\cdot}5$, b ranks 4, thus:

$$H=(a^c_d b)=(1,\ 4,\ 2{\cdot}5,\ 2{\cdot}5).$$

Cook and Seiford (1978) employed the notion of distance to find out the consensus ranking of experts. Suppose there are R number of experts, the ranking of n non-dominated strategies can be obtained after every expert has judged subjectively and made use of the ELECTRE III model. It is indicated by $\{H^f\}_{f=1}^R$. Take:

$$H^f=(a_1^f,\ldots,a_g^f,\ldots,a_n^f),\quad f=1,2,\ldots,R. \tag{28}$$

The equation indicates the preference order of the number f expert, while a_g^f indicates the ranking of the expert towards the No. g non-dominated strategy.

The consensus of R experts can be defined as the minimal ranking of recognition difference by R experts towards the ranking of n non-dominated strategies, and recognition difference can be indicated by distance function $d(H,B)$, that is:

$$d(H,B)=\sum_g |a_g-b_g|, \tag{29}$$

where H and B are the ranking of any two experts. The greatest portion of consensus is demonstrated when minimal cognition differences is revealed by R experts, so consensus ranking can be defined as:

$$M(B)=\sum_{f=1}^{R} d(H^f,B)=\sum_{f=1}^{R}\sum_{g=1}^{n} |a_g^f-b_g|, \tag{30}$$

where B represents the consensus ranking of R experts, while $M(b)$ indicates the ranking as well as the ranking of R experts and recognition difference of the ranking B.

Such problems of consensus ranking can be constructed as assignment problems and be effectively found of its solution. First, it is defined:

$$d_{gh}=\sum_{f=1}^{R} |a_g^f-h|. \tag{31}$$

Since:

$$\sum_{f=1}^{R} d(H^f,B)=\sum_{g=1}^{n_k}\sum_{f=1}^{R} |a_g^f-b_g|. \tag{32}$$

If $b_g=h(h\in\{1,2,\ldots,n\})$, we know that equations (31) and (32) are the combination of the numbered g strategy value, and if it is further defined:

$$Z_{gh}=\begin{cases} 1, \text{ if } b_g=h \\ 0, \text{ otherwise} \end{cases}. \tag{33}$$

Then, to locate consensus ranking problem of the smallest recognition difference, it is very much an assignment problem:

$$\min_{z_{gh}} \sum_{g=1}^{n} \sum_{h-1}^{n} d_{gh} z_{gh} \tag{34a}$$

s.t.

$$\sum_{g=1}^{n} d_{gh} = 1, \quad \forall h \tag{34b}$$

$$\sum_{h=1}^{n} z_{gh} = 1, \quad \forall h \tag{34c}$$

$$Z_{gh} \geqslant 0, \quad \forall_{g,h}. \tag{34d}$$

6. Case study: an example of Taipei city

6.1. PROBLEM DESCRIPTION

The number of vehicles and motorcycles was growing annually at the average percentage of 11·55 and 5·14%, respectively, from 1979 to 1988, in Taipei city. Such a large increase in motor transportation has brought continual deterioration of metropolitan air quality of an almost intolerable extent. Due to strengthened awareness of environmental protection, urban citizens have recently realized the seriousness of air pollution and expect an improvement in air quality to ensure their safety and health. Meanwhile, authorities of municipal administration, discovering the severity of such a problem, have exhausted every means to put forward all possible solutions to improve and control air quality.

In terms of medium- and long-term planning, the solution to the air-pollution problem of Taipei city should move towards legal stipulation and development of pollution control techniques so that the emitted air pollutants of moving vehicles can ultimately be reduced. Medium- and long-term solutions require a tremendous amount of time, manpower and money, during which the air-pollution problem may not necessarily be fully solved. This is due to the close link between air pollution and transportation. Thus, if the air-pollution problem is to be solved, a new transportation means would be required. TSM strategy would be the feasible method to improve air quality in a short span of time. Transportation system management places its focus on management so that the existing transportation facilities can function at their greatest capacities. TSM strategy is for lifting the level of transportation services so as to diminish air pollution, protect urban environment, conserve transportation energy and promote traffic safety as a whole. As a result of these considerations, authorities in municipal administration intend to locate the optimal implementation with the most effective consequences from several feasible TSM strategies, so as to improve the deteriorating air quality of Taipei city in a short period of time.

6.2. THE GENERATING OF TSM STRATEGY AND EVALUATING CRITERIA

Lacking past implementation materials as well as being incapable of putting possible TSM strategy into practice in a trial-and-error manner, planners need to consult broadly with experts from related fields and consider analyses of the application of effective evaluation methods and procedures to determine the most valid and feasible method in such a decision-making environment. A decision-making group was set up to evaluate feasible TSM strategies; experts of the decision-making group were composed of 40 experts from department communications, the Taipei transportation department, the transportation research institute, the environmental protection administration, the Taipei environmental protection department and scholars from related fields.

Experts of the decision-making group, at the onset, applied scenario and brainstorming methods to compile many ideas to construct an hierarchical TSM strategy relevance system. The results of it are shown in Figure 2. According to the common analytical result of the decision-making-group experts, there are total of 33 feasible TSM strategies, which are $A=\{x_1,x_2,\ldots,x_{33}\}$. These strategies can be categorized into two groups: "improving the road system" and "developing an efficient transport system", respectively.

Of the evaluation criteria, they should be able to measure both levels of air pollution and the improvement of transportation. Thus, this paper has chosen six criteria for experts to evaluate TSM strategies, which are: feasibility of implementation, effect of improving air pollution, cost, mitigation of traffic jams, effect of energy conservation and transportation safety. Among them, feasibility of implementation is the most significant judgment criterion; it influences whether in TSM a strategy can be selected as a key criterion to act as a yardstick of preliminary elimination. As for the other five criteria, they performed as yardsticks for detailed evaluation of non-dominated strategies after elimination.

6.3. CONSENSUS ELIMINATION

Forty experts used the key criterion of feasibility of implementation as a base to proceed to pairwise comparison of the 33 TSM strategies and decide which enjoyed higher feasibility of implementation. One binary judgment matrix was obtained from each expert's judgment result. In order to eliminate the views of consensus from these 40 experts, the decision-making group resolved to take $M=20$ after discussion; that is, the majority rule would be over half rule. In other words, should half of these 40 experts share the same view, the advantage and disadvantage of feasible practice of every two TSM strategies could be determined. After integrating ideas from the consensus of these 40 experts, the judgment matrix of consensus was achieved, with its results displayed in Table 1.

The value of $\alpha_j(j=2, 2,\ldots, 33)$ at the extreme right column in Table 1 indicates a superior feasible practice of every TSM strategy to the number of other strategies. A higher level of feasible practice is denoted in comparison to other TSM strategies if the value of α_j becomes greater. The selection criteria of non-dominated strategies was decided after a discussion among the decision-making group, and strategy x_j was selected, or the derived non-dominated strategy after preliminary elimination, as long as $\alpha_j > 10$. After the process of consensus elimination, 10 non-dominated TSM strategies were obtained, which are:

$$A_1=\{x_1, x_3, x_5, x_8, x_9, x_{12}, x_{17}, x_{22}, x_{25}, x_{30}\}.$$

6.4. DETAILED EVALUATION OF NON-DOMINATED STRATEGY

Referring to the 10 non-dominated strategies derived from the first-phase consensus elimination, 40 experts gave their professional judgments on improving air pollution, cost, mitigation of traffic jams, effect of energy conservation and transportation safety,

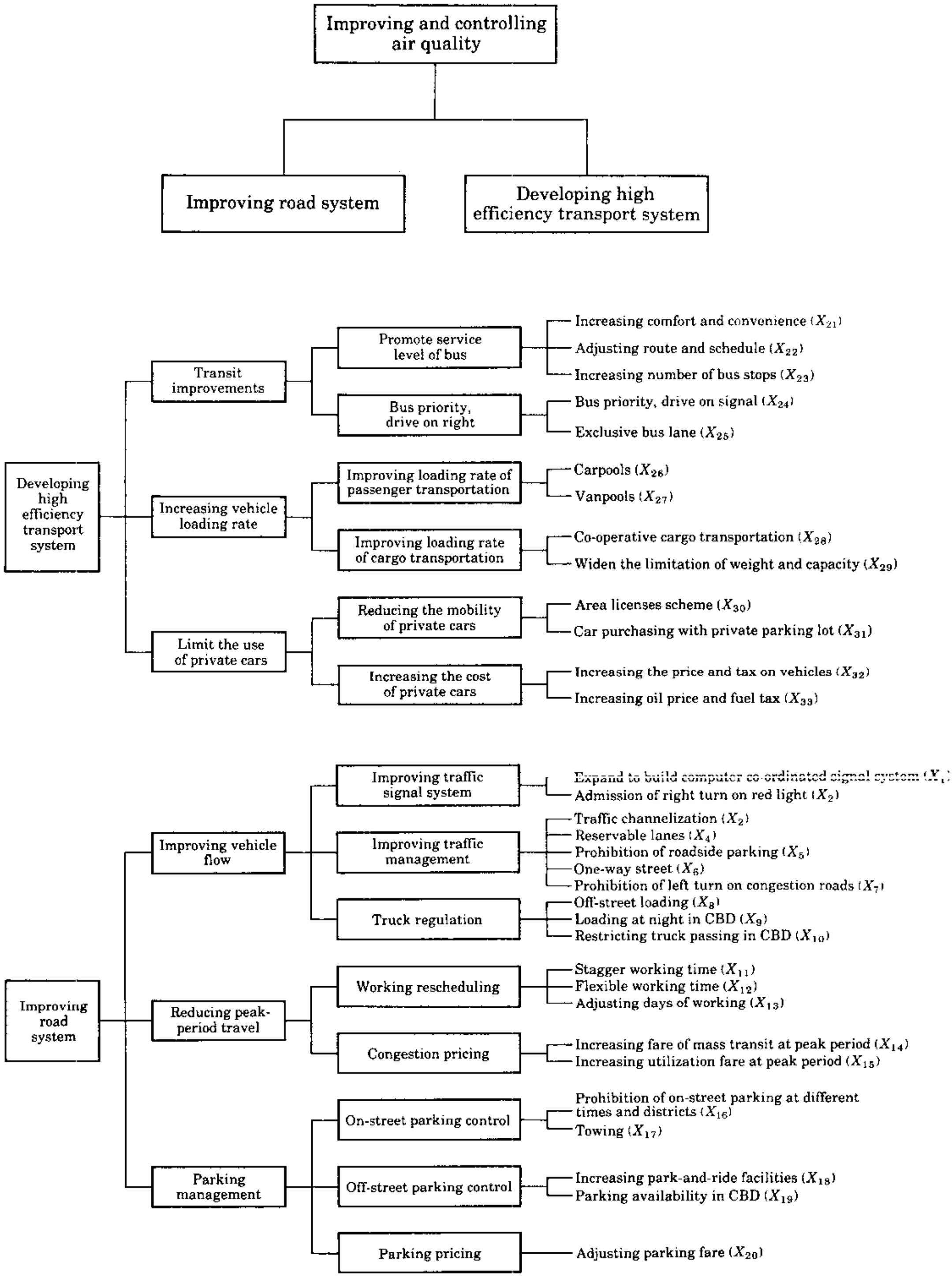

Figure 2. Relevance system of TSM strategies

TABLE 1. Results of consensus elimination

TSM strategies	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}	X_{28}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}	
X_1	1	1	0	1	0	1	1	1	0	1	1	0	0	1	1	0	0	1	1	1	0	0	1	1	1	1	1	0	1	0	1	1	1	22
X_2	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	7
X_3	0	0	1	0	0	1	0	0	0	1	0	0	1	1	1	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	10
X_4	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	0	0	8
X_5	0	1	0	1	1	1	1	0	0	1	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	1	1	1	0	1	1	1	17
X_6	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	8
X_7	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	5
X_8	0	1	1	0	0	1	1	1	0	1	1	0	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1	0	0	0	1	1	0	20
X_9	0	1	0	0	0	1	0	0	1	0	0	0	0	1	0	1	0	1	1	1	1	0	1	1	0	1	0	1	0	1	1	0	1	16
X_{10}	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4
X_{11}	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	6
X_{12}	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	1	0	1	0	0	1	0	0	0	1	0	1	0	1	0	1	12
X_{13}	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	4
X_{14}	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	6
X_{15}	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3
X_{16}	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	5
X_{17}	0	1	0	1	0	1	1	0	0	0	0	0	1	1	0	0	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	11
X_{18}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
X_{19}	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	4
X_{20}	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	1	7
X_{21}	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	6
X_{22}	0	0	1	0	0	1	1	0	0	0	0	1	0	1	1	1	0	1	1	0	0	1	1	1	0	1	0	0	1	0	0	1	0	15
X_{23}	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	4
X_{24}	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	6
X_{25}	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	1	1	1	12
X_{26}	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	1	0	1	9
X_{27}	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	5
X_{28}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
X_{29}	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	4
X_{30}	0	1	0	1	0	1	1	0	0	0	1	0	1	1	1	0	0	1	1	1	0	0	0	0	1	0	0	1	0	1	0	0	0	14
X_{31}	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	3
X_{32}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
X_{33}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2

TABLE 2. Final ranking for each expert

Strategies	Experts																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
X_1	2	1	5	1	3	5	3	4	6	5	3	5	1	3	3	2	6	3	6	4
X_3	1	5	7	7	8	2	4	6	3	3	1	3	1	5	2	3	4	3	4	7
X_5	4	1	1	4	5	4	5	3	1	4	2	1	5	4	1	8	2	2	7	5
X_9	5	2	2	7	1	2	7	6	1	2	4	3	7	5	2	7	1	1	6	9
X_{10}	5	3	6	8	1	6	5	2	1	1	5	4	6	3	1	5	7	2	3	6
X_{12}	7	7	4	4	2	2	6	6	2	2	5	2	4	4	1	5	6	4	7	8
X_{17}	3	4	7	5	7	1	4	1	2	4	3	2	2	5	4	1	3	3	5	4
X_{22}	6	6	3	6	4	1	1	7	4	3	6	1	4	1	2	6	4	6	1	2
X_{25}	7	8	5	2	9	3	4	9	5	3	7	3	3	2	5	9	4	5	2	3
X_{30}	4	6	8	3	6	2	2	5	2	3	4	2	4	2	4	4	5	4	3	1

Strategies	Experts																			
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
X_1	6	1	3	7	4	2	4	4	1	3	5	8	6	1	1	2	1	3	1	4
X_3	1	6	2	5	6	5	8	7	2	6	4	2	5	4	4	8	8	1	6	7
X_5	5	5	6	1	1	5	3	5	3	5	2	4	4	3	2	4	2	4	4	3
X_9	3	3	7	5	2	7	6	1	4	8	2	6	5	2	5	3	6	7	7	6
X_{10}	2	2	5	3	3	4	5	3	4	4	1	7	2	2	2	6	2	4	5	1
X_{12}	7	2	4	6	5	3	7	8	7	9	6	5	2	2	6	7	5	5	2	6
X_{17}	8	8	2	8	6	3	4	4	7	5	4	9	1	2	3	4	7	6	5	1
X_{22}	9	4	3	2	6	1	2	6	6	1	3	5	4	4	6	5	3	2	3	7
X_{25}	7	4	1	4	7	2	1	2	4	2	5	3	3	6	5	1	4	3	4	2
X_{30}	4	7	1	8	3	6	1	3	5	7	2	1	3	5	3	4	4	6	3	5

and provided each with a qualitative measurement value of 1–10. The greater the measurement value, the higher the level of achievement. However, this is reversed when it comes to the cost criterion. A larger measurement value indicates a higher cost. Therefore, if this paper utilizes 10 minus the cost criterion measurement value, it would focus every criterion in the same direction so at to arrive at the measurement value with equal comparison foundation. For weights of the five evaluation criteria, every expert can locate them according to the eigenvalue method (Saaty, 1977).

Based upon weights of criteria and measurement value of every criterion, the ELECTRE III model can be used to find out the ranking of the 10 non-dominated strategies from every expert. As for the threshold value, it can be ascertained from the 40 experts individually. For instance, if one expert should decide the values of indifference threshold, preference threshold and veto threshold are 1, 3 and 5, respectively, the ranking results of the 40 experts can be resolved separately after the evaluation of the ELECTRE III model. Since the derived ranking through the ELECTRE III model is of partial ordinal ranking, ties can be found in ranking.

6.5. CONSENSUS RANKING

Since 40 experts think differently about these 10 non-dominated strategies, different rankings from their evaluation results are calculated. Then how can the most consensus

TABLE 3. Total cognitional distance (d_{gh}) among experts

	Ranking									
Strategies	1	2	3	4	5	6	7	8	9	10
X_1	149	125	110	102	102	114	132	153	179	211
X_3	203	172	146	123	102	94	93	103	124	157
X_5	150	118	99	89	89	94	112	138	171	210
X_9	179	150	129	118	111	111	114	127	151	181
X_{10}	220·5	180·5	147·5	120·5	101·5	89·5	84·5	94·5	109·5	139·5
X_{12}	159	125	106	98	99	105	116	137	167	201
X_{17}	186·5	154·5	124·5	103·5	90·5	93·5	104·5	117·5	139·5	94
X_{22}	172·5	141·5	119·5	102·5	89·5	92·5	103·5	123·5	153·5	187·5
X_{25}	189·5	152·5	125·5	106·5	93·5	92·5	106·5	106·5	119·5	138·5
X_{30}	170·5	136·5	107·5	87·5	81·5	88·5	124·5	124·5	152·5	189·5

TABLE 4. Consensus ranking

	Ranking									
Strategies	1	2	3	4	5	6	7	8	9	10
X_1	1	0	0	0	0	0	0	0	0	0
X_3	0	0	0	0	0	0	1	0	0	0
X_5	0	0	1	0	0	0	0	0	0	0
X_9	0	0	0	0	0	0	0	0	0	1
X_{10}	0	0	0	0	0	1	0	0	0	0
X_{12}	0	1	0	0	0	0	0	0	0	0
X_{17}	0	0	0	0	0	0	0	0	1	0
X_{22}	0	0	0	0	1	0	0	0	0	0
X_{23}	0	0	0	0	0	0	0	1	0	0
X_{30}	0	0	0	1	0	0	0	0	0	0

ranking be found from these 40 different rankings of 40 experts? This paper applied the ranking method of consensus proposed by Cook and Seiford (1978) so as to find out the most intimate recognition ranking from these 40 experts. From the partial ordinal ranking obtained through the evaluaton of the ELECTRE III model by these 40 experts, the distance matrix (d_{gh}) of recognition difference of these 40 experts can be derived (as shown in Table 3). In the end, the assignment problem of equation (34) can be constucted based on this distance matrix. Results are shown in Table 4 when solutions have been found, indicating consensus ranking B as:

$$B=[x_1, x_5, x_{12}, x_{30}, x_{22}, x_{17}, x_9, x_3, x_{10}, x_{25}].$$

From the illustration of this consensus ranking, the three TSM strategies of "expand to build computer co-ordinated signal system (x_1)", "prohibition of roadside parking (x_5)" and "flexible working time (x_{12})" are strategies with higher feasibility and greater achievable results in terms of improving and controlling the air pollution of Taipei city.

7. Conclusions

The deterioration of air quality in a big city is closely related to transporation. Due to an increasing number of motor vehicles, air quality in the metropolitan area has worsened. In view of such a situation, transportation is the cause of air pollution, while the deterioration of air quality is the consequence of transportation development. To improve and control air pollution of urban areas, the point of attack has to be enacted from the perspective of traffic and transportation. Though the application of a TSM strategy results in a low-cost improvement policy for the traffic and transportation in a short span of time, it would not be useful to measure those various TSM strategies qualitatively one by one. Therefore, the pooling of expert views from diverse expertise is a feasible way to discover a strategy of consensus from judgments of several different professional fields.

This paper proposes a three-phase evaluation model, which first proceeds with consensus elimination for finding out non-dominated strategies under one certain key criterion; next, the ELECTRE III model is exploited by experts respectively to rank non-dominated strategy under multiple criteria; and, last, the consensus ranking of Cook and Seiford (1978) is employed to find out the highest consensus ranking from all experts. This paper, from the case study of Taipei city, demonstrates the robustness of this evaluation process, which is very useful in terms of qualitative or mixed-data expert evaluation. For even more precise measurement, these consensus rankings that stand ahead can be further evaluated by CBA or CEA methods so that a more objective evaluation result can be obtained.

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